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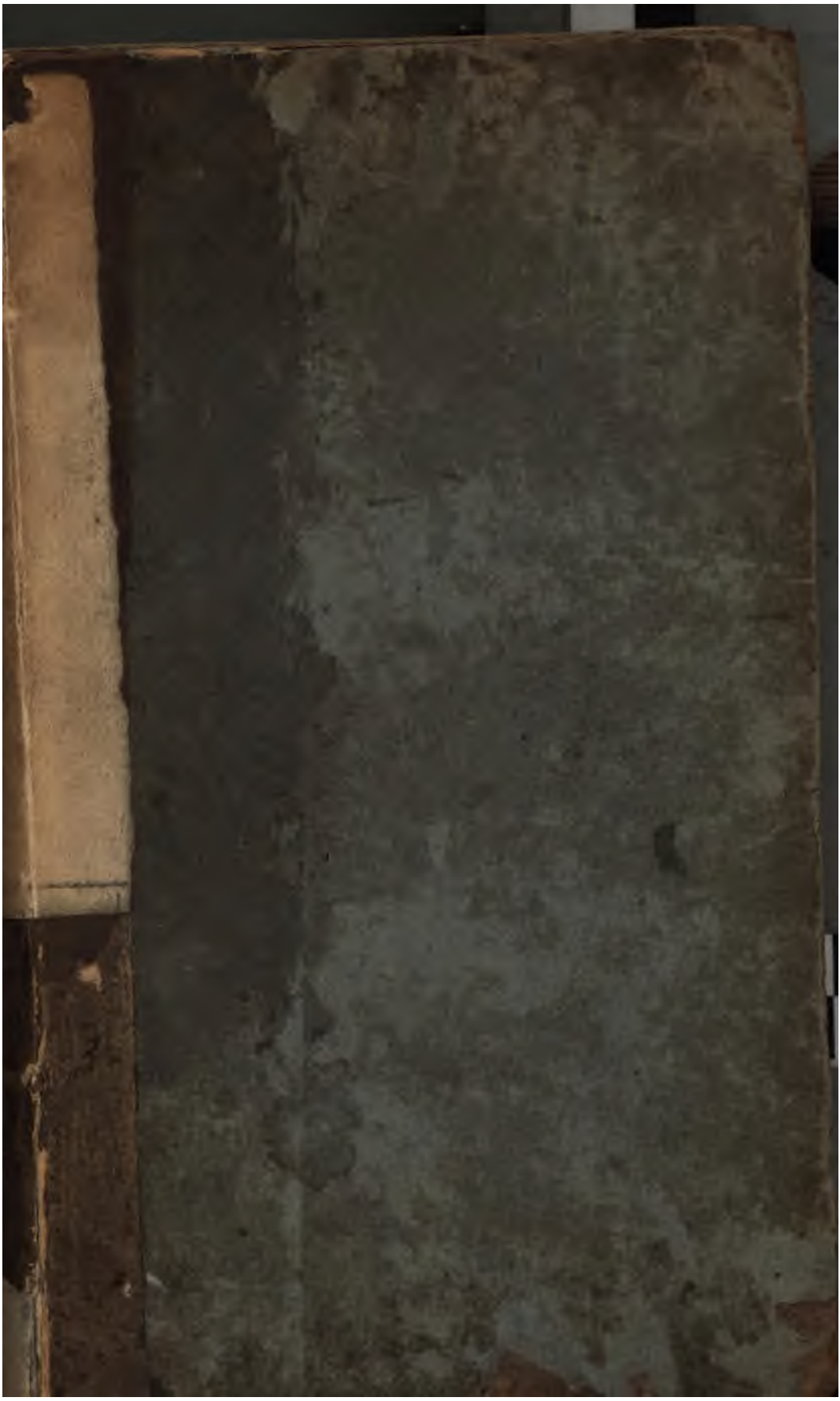

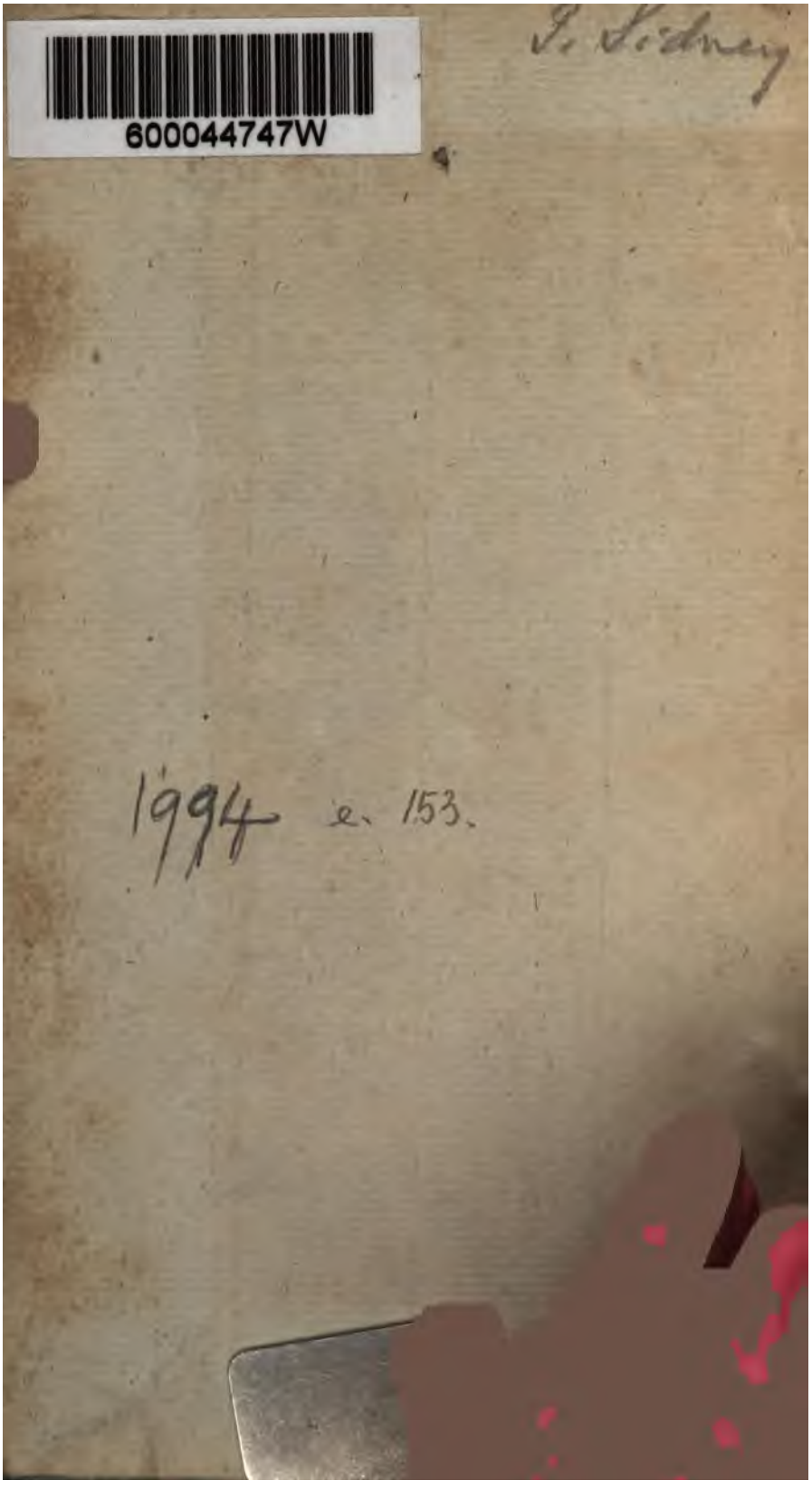
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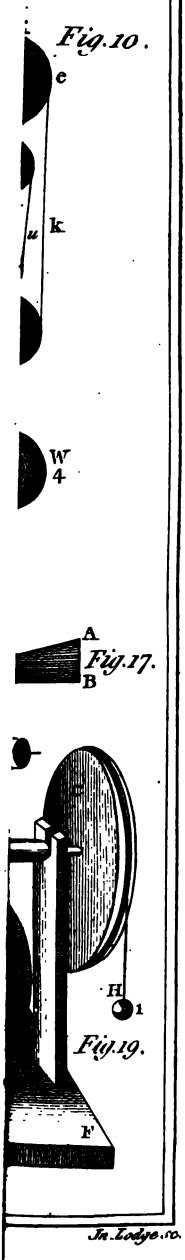

THE

SCHOOL OF ARTS;

OR, AN

Introduction to Useful Knowledge:

BEING A COMPILATION OF

REAL EXPERIMENTS AND IMPROVEMENTS,

IN SEVERAL

PLEASING BRANCHES OF SCIENCE,

ON THE FOLLOWING SUBJECTS, VIZ.

Mechanics,
Electricity,
Pneumatics,
Hydroſtatics and Hydraulics,
Optics,
Clock and Watch-making,
and
Aſtronomy.

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THE FOURTH EDITION,
WITH VERY CONSIDERABLE ADDITIONS.

By JOHN IMISON.

London:
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TO

SAMUEL MORE, Eſq.

Secretary to the Society inſtituted at London, for the Encouragement of Arts, Manufactures, and Commerce.

SIR,

IT is with propriety that the following pages are inſcribed to you. A Treatiſe upon the Arts ſhould have a Patron who underſtands the ſubject. No perſon will deny that you are competent to judge upon this point. And although I acknowledge my diffidence, when I think that my Work is to be ſubmitted to a perſon of your ſkill and diſcernment, yet I own that I am in

ſome degree flattered, that my performance is not wholly deſtitute of merit, ſince you are kind enough to accept what I now preſent.

It is with pleaſure alſo that I take this opportunity of publicly acknowledging the obligations I lie under to your friendſhip and good offices in many inſtances, and that I am, with gratitude and eſteem,

SIR,

Your obedient

and very humble ſervant,

John Imiſon.

THE PREFACE.

WHEN I first compiled the following sheets, they were not intended for the press, but for my private amusement, because they contained the principal matters of what I had either read, seen, or experienced; or indeed what accorded to my inclination upon these subjects. I laboured daily to increase my little store; and, having an extensive apparatus, I carefully proved every experiment before I gave it a place in my repository. I have also tried a variety of other experiments from Smith, Barrow, Salmon, &c. &c. without the desired success; which was one principal motive for the present publication, as it is my wish that my labours may prove useful to those whose ingenuity may lead them to practise and improve upon my experience. — I have given, without reserve, the best descriptions I could collect of every thing I have treated; and I can affirm, that every page in the book contains matter of real value when applied to practice.

Numerous

Numerous are the authors who have written upon the miſcellaneous part of theſe ſubjects; but few of them have proved by actual experiment what they have aſſerted; and indeed this is not to be wondered at, when it is known that experiments are attended with much expence. And although I have uſed my beſt endeavours, yet I will not aſſert but that better methods, in ſeveral things, may be diſcovered: nevertheleſs, the reader may rely that the facts I have advanced will bear the teſt of any enquiry.

The particular branches of ſcience which I have endeavoured to explain, are thoſe of the Mechanical Powers, Electricity, Pneumatics, Hydroſtatics and Hydraulics, Optics, and Aſtronomy; a treatiſe on Clock-making, the nature, uſe, and conſtruction of the Barometer, and the conſtruction of optical and many philoſophical inſtruments; all which, I flatter myſelf, the ſtudents will find to be exact, whether they are conſulted with a view to theory or practice.

A knowledge of the mechanic powers is now become a part of polite education; and their utility is manifeſted by daily experience; therefore ſuch definitions, poſtulates, and axioms, are premiſed as were thought neceſſary to form a right conception of the principles, ſo as to form a juſt idea of their application on any particular occaſion; and as my reaſoning on theſe ſubjects has been general, ſo no regard has been paid to the weight of the beam or lever, it being well known

known that theſe muſt be equipoiſed before ſuch theorems can be applied.

So many books have been written upon the ſubject of the Arts and Sciences, that any perſon would imagine that more would be ſuperfluous. Books, however, which have been written by authors of credit, are very expenſive and very voluminous; and it would take too much time to read over and attain a thorough knowledge of the doctrine they contain. In the preſent performance every thing is rendered familiar to the meaneſt capacity; and with a little practice and perſeverance, the moſt illiterate artizan cannot fail of making a conſiderable progreſs in almoſt every art and ſcience it treats of: beſides, every artificer cannot furniſh himſelf eaſily with the beſt authors upon all the ſubjects contained in this Work; the expence of which and waſte of time, would be too conſiderable. I have inſerted not only known uſeful rules upon the ſubjects I have noticed, but a great many others that are entirely new, and of very great uſe, both in theory and practice, to the working mechanic.

I pretend not to communicate my ideas with the embelliſhments of elegant language; my employment as a mechanic pleading an excuſe for errors or inaccuracies in this reſpect; but I have endeavoured to be plain, exact, and intelligible, and my meaning will

not

not be miſunderſtood by thoſe who pay competent attention to my book.

In the Miſcellaneous part of this performance, many ſecrets are diſcovered that are worthy of attention; a great number of which were never before publiſhed. Some apology may be thought neceſſary for divulging them; but as I obtained my knowledge chiefly by my own induſtry and unwearied application, I have a right to communicate it for the benefit of young experimenters, till they can procure better aſſiſtance, or be enabled to ſtrike out better methods of improvement by their own experience. At a future period I intend to publiſh another Volume, as an Appendix to this; wherein I ſhall lay down every calculation in different mill-works, water-works, ſteam-engines, &c. together with a variety of uſeful rules for the working mechanic; to which I ſhall alſo add ſundry Miſcellaneous Articles.

The moſt valuable improvements in arts and ſciences which have appeared of late years, are, 1. Meſſ. Watts and Bolton's Steam-Engine; *a brief deſcription of which I have given in the following Treatiſe:* 2. The Rev. Mr. Cooke's Drill-Plough *; *and although I have not admitted an account of it in this Treatiſe, yet I cannot help obſerving concerning it,*

* See Deſcription in his Drill Huſbandry perfected, price 1s. publiſhed by Mr. Murray; alſo, Young's Memoirs of Agriculture, &c.

that

that it is an aſſemblage of the mechanic powers ſimply diſpoſed to great advantage, ſo as to aſſiſt that important deſign of the inventor, the improvement of agriculture, in the beſt manner yet attempted: 3. A Teleſcope: *which is the moſt noble inſtrument of the kind ever conſtructed, and which diſplays Dr. Herſchell's optical and aſtronomical abilities beyond all of his cotemporaries.*

Before I conclude, I muſt acknowledge my obligations to Mr. James Wood, *oppoſite the Sunday Toll-Bar, Kent-ſtreet Road, Southwark, late Collector for the London Bridge Water-Works; whoſe extenſive knowledge, both in theory and practice, of every ſcience, is greater than is generally to be met with united in one perſon; and to him I would recommend thoſe gentlemen who are in want of curious models in every branch of experimental philoſophy.*

MECHANICS.

DEFINITIONS.

1. MECHANICS is a ſcience which treats of the forces, motions, velocities, and in general, of the actions of bodies upon one another; it teaches how to move any given weight with any given power; how to contrive engines to raiſe great weights, or to perform any kind of motion.

2. Body, is the maſs or quantity of matter; an elaſtic body is that which yields to a ſtroke, and recovers its figure again; otherwiſe, it is called an unelaſtic body.

3. Denſity, is the proportion of the quantity of matter in any body to the quantity of matter in another body of the ſame dimenſions.

4. Force, is a power exerted on a body to move it; if it act inſtantaneouſly, it is called percuſſion, or impulſe; if conſtantly, it is an accelerative force.

5. Velocity, is a property of motion, by which a body paſſes over a certain ſpace in a certain time; and is

greater or leſs, as it paſſes over a greater or leſs ſpace in a certain time: ſuppoſe a ſecond.

6. Motion, is a continual and ſucceſſive change of place. If the body moves equally, it is called equable or uniform motion; if it increaſes or decreaſes, it is called accelerated or retarded motion; when it is compared with a body at reſt, it is called abſolute motion; but when compared with a body in motion, it is called relative motion.

7. Direction of motion, is the courſe or way the body tends, or the line it moves in.

8. Quantity of motion, is the motion a body has, conſidered both in regard to its velocity and quantity of matter. This is called the momentum of a body.

9. Vis inertiæ, is the innate force of matter, by which it reſiſts any change, ſtriving to preſerve its preſent ſtate of reſt or motion.

10. Gravity, is that force wherewith a body endeavours to fall downwards; it is called abſolute gravity in empty ſpace; and relative gravity when immerſed in a fluid.

11. Specific Gravity, is the greater or leſs weight of bodies of the ſame magnitude, or the proportion between their weights. This proceeds from the natural denſity of bodies.

12. Center of gravity, is a certain point of a body upon which the body, when ſuſpended, will reſt in any poſition.

13. Center

13. Center of motion, is a fixed point, round about which a body moves; and the axis of motion is a fixed line it moves about.

14. Power and weight, when oppoſed to one another, ſignify the body that moves another, and the other which is moved; the body which begins and communicates motion is the power; and that which receives the motion is the weight.

15. Equilibrium, is the balance of two or more forces, ſo as to remain at reſt.

16. Machine or engine, is any inſtrument to move bodies; made of levers, wheels, pullies, &c.

17. Mechanic powers, are the lever, wheel, pulley, ſcrew, wedge, and the inclined plane.

18. Streſs, is the effect any force has to break a beam, or any other body; and the ſtrength is the reſiſtance it is able to make againſt any ſtraining force.

19. Friction, is the reſiſtance which a machine ſuffers, by the parts rubbing againſt one another.

POSTULATA.

1. That a ſmall part of the ſurface of the earth may be looked upon as a plane; for though the earth be round, yet ſuch a ſmall part of it as we have any occaſion to conſider, does not ſenſibly differ from a plane.

2. That heavy bodies deſcend in lines parallel to one another; for though they all tend to a point, which is the center of the earth, yet that center is at ſuch a diſtance, that theſe lines differ inſenſibly from parallel lines.

3. The ſame body is the ſame weight in all places on or near the earth's ſurface; for the difference is not ſenſible in the ſeveral places we can go to.

4. Though all matter is rough, and all engines imperfect; yet, for the eaſe of calculation, we muſt ſuppoſe all planes perfectly even; all bodies perfectly ſmooth; and all bodies and machines to move without friction or reſiſtance; all lines ſtraight and inflexible, without weight or thickneſs; cords extremely pliable, and ſo on.

AXIOMS.

1. Every body endeavours to remain in its preſent ſtate, whether it be at reſt, or moving uniformly in a right line.

2. The alteration of motion by any external force, is always proportionable to that force, and in direction of the right line in which the force acts.

3. Action and re-action between any two bodies, are equal and contrary.

4. The motion of any body is made up of the ſum of the motions of all the parts.

5. The

5. The weights of all bodies in the ſame place, are proportional to the quantities of matter they contain, without any regard to their figure.

6. The vis inertiæ of any body, is proportional to the quantity of matter.

7. Every body will deſcend to the loweſt place it can get to.

8. Whatever ſuſtains a heavy body, bears all the weight of it.

9. Two equal forces acting againſt one another in contrary directions, deſtroy one another's effect; and unequal forces act only with the difference of them.

10. When a body is kept in equilibrium, the contrary force in any line of direction is equal.

11. If a certain force generate any motion, an equal force acting in a contrary direction, will deſtroy as much motion in the ſame time.

12. If a body be acted on by any power in a given direction, it is all one in what point of that line of direction the power is applied.

13. If a body is drawn by a rope, all the parts of the rope are equally ſtretched; and the force in any part acts in direction of that part; and it is the ſame thing whether the rope is drawn out at length, or goes over ſeveral pullies.

14. If

14. *If ſeveral forces at one end of a lever act againſt ſeveral forces at the other end, the lever acts, and is acted on, in direction of its length.*

Of the Mechanical Powers.

11 NOW, if we conſider bodies in motion, and compare them together, we may do this either with reſpect to the quantities of matter they contain, or the velocities with which they are moved; for the heavier any body is, the greater is the power required either to move or ſtop its motion: and again, the ſwifter it moves, the greater is its force: ſo that the whole force of a moving body is the reſult of its quantity of matter multiplied by the velocity with which it is moved: and when the product ariſing from the multiplication of the particular quantities of matter in any two bodies, by their reſpective velocities, are equal, the entire forces are ſo too. Thus, ſuppoſe a body, which we call A, to weigh 40 pounds, and to move at the rate of two miles in a minute; and another body, which we call B, to weigh only 4 pounds, and to move 20 miles in a minute; the entire forces with which theſe two bodies would ſtrike againſt any obſtacle would be equal to each other, and therefore it would require equal powers to ſtop them: for 40 multiplied by 2 gives 80, the force of the body A; and 20 multiplied by 4 gives 80, the force of the body B. Upon this eaſy principle depends the whole of mechanics: and it holds univerſally true, that when two bodies are ſuſpended on any machine, ſo as to act contrary to each other; if the machine be put

put into motion, and the perpendicular aſcent of one body multiplied into its weight, be equal to the perpendicular deſcent of the other body multiplied into its weight, thoſe bodies, how unequal ſoever in their weights, will balance one another in all ſituations: for, as the whole aſcent of one is performed in the ſame time with the whole deſcent of the other, their reſpective velocities muſt be directly as the ſpaces they move through; and the exceſs of weight in one body is compenſated by the exceſs of velocity in the other. Upon this principle, it is eaſy to compute the power of any mechanical engine, whether ſimple or compound; for it is but only finding how much ſwifter the power moves than the weight does (*i. e.* how much farther in the ſame time); and juſt ſo much is the power increaſed by the help of the engine.

How to compute the power of any mechanical engine.

In the theory of this ſcience we ſuppoſe all planes perfectly even, all bodies perfectly ſmooth, levers to have no weight, cords to be extremely pliable, machines to have no friction; and, in ſhort, all imperfections muſt be ſet aſide until the theory be eſtabliſhed; and then, proper allowances are to be made.

The ſimple machines, uſually called mechanical powers, are ſix in number, viz. the lever, the wheel and axle, the pulley, the inclined plane, the wedge, and the ſcrew. They are called mechanical powers, becauſe they help us mechanically to raiſe weights, move heavy bodies, and overcome reſiſtances, which we could not effect without them.

The mechanic powers what.

1. A lever is a bar of iron or wood, one part of which being ſupported by a prop, all the other parts turn upon that prop as their center of motion: and the velocity of every

Of the lever

every part or point is directly as its diſtance from the prop. Therefore, when the weight to be raiſed at one end is to the power applied to the other to raiſe it; as the diſtance of the power from the prop is to the diſtance of the weight from the prop, the power and weight will exactly balance or counterpoiſe each other: and as a common lever has nearly no friction on its prop, a very little additional power will be ſufficient to raiſe the weight.

There are four kinds of levers. 1. The common ſort, when the prop is placed between the weight and power; but much nearer to the weight than to the power. 2. When the prop is at one end of the lever, the power at the other, and the weight between them. 3. When the prop is at one end, the weight at the other, and the power applied between them. 4. The bended lever, which differs only in form from the firſt ſort, but not in property. Thoſe of the firſt and ſecond kind are often uſed in mechanical engines; but there are few inſtances in which the third ſort is uſed.

The balance.

The balance is a ſtraight inflexible rod or beam, turning round a fixed point or axle in the middle of it, to be loaded at each end with weights ſuſpended there: it is by ſome reckoned a lever of the firſt kind; but as both ends are ſet at equal diſtances from its center of motion, they move with equal velocities; and therefore, as it gives no mechanical advantage, it cannot properly be reckoned among the mechanical powers.

Plate I. Fig. 5.

Let C D be a beam or lever, E the middle point or center of motion; A B the weights, hanging at the ends C D; then let the beam and the weights, or the whole machine,

machine, be ſuſpended at E; and ſuppoſe the beam and the weights be turned upon the center E, then the points C D being equidiſtant from E, will deſcribe equal arches, and therefore their velocities will be equal; and if the bodies A and B be equal, then the motion of A will be equal to the motion of B, as the quantities of matter and velocities are equal; and conſequently, if the beam and weights are ſet at reſt, neither of them can move the other, but they will remain in equilibrium. If one weight be greater than the other, that weight and ſcale will deſcend and raiſe the other.

Now, the uſe of the balance, or a common pair of ſcales, is to compare the weights of different bodies; for any body, whoſe weight is required, put into one ſcale, and balanced by known weights put into the other ſcale, theſe weights will ſhew the weight of the body.

The Properties of Scales.

To have a pair of ſcales perfect, they muſt have theſe properties: 1. The points of ſuſpenſion of the ſales, and the center of motion of the beam C, E, D, muſt be in a right line. 2. The arms C E, D E, muſt be of equal length from the center. 3. That the center of gravity be in the center of the motion E. 4. That there be as little friction as poſſible. 5. That they be in equilibrium when empty.

If the center of gravity of the beam be above the center of motion and the ſcales be in equilibrium; if they be put a little out of that poſition, by putting down one end of the beam, that end will continually deſcend until it be ſtopt at the handle H; for by that motion, the center of gravity is continually deſcending, according to the nature of it; but if the center of

gravity of the beam be below the center of motion; if one end of the beam be put down a little, to deſtroy the equilibrium, it will return back and vibrate up and down; for by the motion the center of gravity is endeavouring to deſcend.

To prove Scales whether they are good.

To diſcover a falſe balance, make the weights in the two ſcales to be in equilibrium; then change the weights to the contrary ſcales, and if they be not in equilibrium, the balance is falſe.

Hence alſo to prove a pair of good ſcales, they muſt be in equilibrium when empty, and likewiſe in equilibrium with the two weights. Then, if the two weights be changed to the contrary ſcales, the equilibrium will ſtill remain, if the ſcales are good.

Fig. 1. The firſt kind of lever.

A lever of the firſt kind is repreſented by the bar A B C, ſupported by the prop D. Its principal uſe is to looſen large ſtones in the ground, or to raiſe great weights to ſmall heights, in order to have ropes put under them for raiſing them higher by other machines. The parts A B and B C on different ſides of the prop D, are called the arms of the lever: the end A of the ſhorter arm A B being applied to the weight intended to be raiſed, or to the reſiſtance to be overcome; and the power applied to the end C of the longer arm B C.

In making experiments with this machine, the ſhorter arm A C muſt be as much thicker than the longer arm B B, as will be ſufficient to balance it on the prop D. This ſuppoſed, let P repreſent a power whoſe gravity is equal to 1 ounce, and W a weight, whoſe gravity is equal

equal to 12 ounces. Now if the power be twelve times as far from the prop as the weight is, they will exactly counterpoiſe; and a ſmall addition to the power P will cauſe it to deſcend, and raiſe the weight W; and the velocity with which the power deſcends will be to the velocity with which the weight riſes, as 12 to 1; that is, directly as their diſtances from the prop, and, conſequently, as the ſpaces through which they move. Hence it is plain, that a man who, by his natural ſtrength, without the help of any machine, could ſupport an hundred weight, will by the help of this lever be enabled to ſupport twelve hundred. If the weight be leſs, or the power greater, the prop may be placed ſo much farther from the weight; and then it can be raiſed to a proportionable greater height. For, univerſally, if the intenſity of the weight multiplied into its diſtance from the prop, be equal to the intenſity of the power multiplied into its diſtance from the prop, the power and weight will exactly balance each other; and a little addition to the power will raiſe the weight. Thus, in the preſent inſtance, the weight W is 12 ounces, and its diſtance from the prop is 1 inch; and 12 multiplied by 1 is 12; the power P is equal to 1 ounce, and its diſtance from the prop is 12 inches, which multiplied by 1 is 12 again; and therefore there is an equilibrium between them. So, if a power equal to 2 ounces be applied at the diſtance of 6 inches from the prop, it will juſt balance the weight W; for 6 multiplied by 2 is 12, as before; and a power equal to 3 ounces placed at 4 inches diſtant from the prop would be the ſame; for 3 times 4 is 12; and ſo on, in proportion. To this kind of lever may be reduced ſeveral ſorts of inſtruments, ſuch as ſciſſars, pincers, ſnuffers, &c. which are made of two levers acting contrary to one another: their prop or center of motion being the pin which keeps

Fig. 1.

Properties of the firſt kind of lever.

them together. In common practice, the longer end of this lever greatly exceeds the weight of the ſhorter: which gains great advantage, becauſe it adds ſo much to the power.

Fig. 1. The ſteelyard.

The ſtatera, or Roman ſteelyard, is a lever of this kind, and is uſed for finding the weights of different bodies by one ſingle weight placed at different diſtances from the prop or center of motion D. For, if a weight hangs at A, the extremity of the ſhorter arm D G is of ſuch a weight as will exactly counterpoiſe the longer arm D X; if this arm be divided into as many equal parts as it will contain, each equal to O D, the ſingle weight P (which we may ſuppoſe to be 1 pound) will ſerve for weighing any thing as heavy as itſelf, or as many times heavier as there are diviſions in the arm D X, or any quantity between its own weight and that quantity. As for example: If P be 1 pound, and placed at the firſt diviſion 1 in the arm D X, it will balance 1 pound in the ſcale at W; if it be removed to the ſecond diviſion at 2, it will balance 2 pounds in the ſcale; if to the third, 3 pounds; and ſo on to the end of the arm D X. If each of theſe integral diviſions be ſubdivided into as many equal parts as a pound contains ounces, and the weight P be placed at any of theſe ſubdiviſions, ſo as to counterpoiſe what is in the ſcale, the pounds and odd ounces therein will by that means be aſcertained.

Fig. 2.

A lever of the ſecond kind has the weight between the prop and the power. In this, as well as the former, the advantage gained is as the diſtance of the power from the prop to the diſtance of the weight from the prop: for the reſpective velocities of the power and weights are in that proportion; and they will balance each

each other when the intenſity of the power, multiplied by its diſtance from the prop, is equal to the intenſity of the weight multiplied by its diſtance from the prop. Thus, if A B be a lever on which the weight W of 6 ounces hangs at the diſtance of 1 inch from the prop G, and a power P, equal to the weight of 1 ounce, hangs at the end B, 6 inches from the prop; by the cord C D going over the fixed pulley E, the power will juſt ſupport the weight: and a ſmall addition to the power will raiſe the weight 1 inch for every 6 inches that the power deſcends. This lever ſhews the reaſon why two men carrying a burden upon a ſtick between them, bear unequal ſhares of the burden in the inverſe proportion of their diſtances from it. For it is well known, that the nearer either of them is to the burden, the greater ſhare he bears of it: and if he goes directly under it, he bears the whole. So if one man be at G, and the other at B, having the pole or ſtick A B reſting on their ſhoulders; if the burden or weight W be placed five times as near the man at G as it is to the man at B, the former will bear five times as much weight as the latter.

Properties of the ſecond kind of lever.

This is likewiſe applicable to the caſe of two horſes of unequal ſtrength to be ſo yoked, as that each horſe may draw a part proportionable to his ſtrength; which is done by ſo dividing the beam they pull, that the point of traction may be as much nearer to the ſtronger horſe than to the weaker, as the ſtrength of the former exceeds that of the latter.

To this kind of lever may be reduced oars, rudders of ſhips, doors turning upon hinges, cutting-knives which are fixed at the point, &c.

The third kind of lever.

If in this lever we ſuppoſe the power and weight to change

change places, ſo that the power may be between the weight and the prop, it will become a lever of the third kind; in which, that there may be a balance between the power and the weight, the intenſity of the power muſt exceed the intenſity of the weight juſt as much as the diſtance of the weight from the prop exceeds the diſtance of the power. Thus, let E be the prop of the lever A B, and W a weight of 1 pound, placed 3 times as far from the prop as the power P acts at F, by the cord C going over the fixed pulley D: in this caſe, the power muſt be equal to 3 pounds, in order to ſupport the weight of 1 pound.

Fig. 3.

Properties of the third kind of lever.

To this ſort of lever are generally referred the bones of a man's arm; for when he lifts a weight by the hand, the muſcle that exerts its force to raiſe that weight, is fixed to the bone about one tenth part as far below the elbow as the hand is. And the elbow being the center round which the lower part of the arm turns, the muſcle muſt therefore exert a force ten times as great as the weight that is raiſed.

As this kind of lever is a diſadvantage to the moving power, it is uſed as little as poſſible; but in ſome caſes it cannot be avoided; ſuch as that of a ladder, which, being fixed at one end, is by the ſtrength of a man's arms reared againſt a wall.

And in clock-work, where all the wheels may be reckoned levers of this kind, becauſe the power that moves every wheel, except the firſt, acts upon it near the center of motion by means of a ſmall pinion; and the reſiſtance it has to overcome, acts againſt the teeth round its circumference.

The fourth kind of lever.

The fourth kind of lever differs nothing from the firſt but in being bended for the ſake of convenience. ACB

Fig. 4.

is

is a lever of this ſort, bended at C, which is its prop or center of motion. P is a power acting upon the longer arm A C at F, by the means of the cord D E going over the pulley G; and W is a weight or reſiſtance acting upon the end B of the ſhorter arm C B. If the power is to the weight as C B is to C F, they are in equilibrium. Thus: Suppoſe W to be 5 pounds acting at the diſtance of one foot from the center of motion C, and P to be 1 pound acting at F, five feet from the center C, the power and weight will juſt balance each other. A hammer drawing a nail is a lever of this ſort.

2. The ſecond mechanical power is the wheel and axle, in which the power is applied to the circumference of the wheel, and the weight is raiſed by a rope which coils about the axle as the wheel is turned round. Here it is plain, that the velocity of the power muſt be to the velocity of the weight as the circumference of the wheel is to the circumference of the axle: and conſequently, the power and weight will balance each other, when the intenſity of the power is to the intenſity of the weight as the circumference of the axle is to the circumference of the wheel. Let A B be a wheel, C D its axle, and ſuppoſe the circumference of the wheel to be 8 times as great as the circumference of the axle; then, a power P equal to 1 pound, hanging by the cord I, which goes round the wheel, will balance a weight W of 8 pounds hanging by the rope K, which goes round the axle. And as the friction on the pivots or gudgeons of the axle E F is but ſmall, a ſmall addition to the power will cauſe it to deſcend, and raiſe the weight; but the weight will riſe with only an eighth part of the velocity wherewith the power deſcends, and conſequently, through no more than one eighth part of an equal ſpace in the ſame time. If the wheel be pulled round by the handles S, S, the

The wheel and axle.

Fig. 7.

Fig. 7.

the power will be increaſed in proportion to their length. And by this means, any weight may be raiſed as high as the operator pleaſes.

Its uſes.

To this ſort of engine belong all cranes for raiſing great weights; and in this caſe, the wheel may have cogs all round it inſtead of handles, and a ſmall lanthorn or trundle may be made to work in the cogs, and be turned by a winch; which will make the power of the engine to exceed the power of the man who works it, as much as the number of revolutions of the winch exceeds thoſe of the axle C D, when multiplied by the exceſs of the length of the winch above the length of the ſemidiameter of the axle, added to the ſemidiameter or half thickneſs of the rope K, by which the weight is drawn up. Thus: Suppoſe the diameter of the rope and axle taken together, to be 13 inches, and conſequently, half their diameter to be 6 ½ inches; ſo that the weight W will hang at 6 ½ inches perpendicular diſtance from below the center of the axle. Now, let us ſuppoſe the wheel A B, which is fixed on the axle, to have 80 cogs, and to be turned by means of a winch 6 ½ inches long, fixed on the axle of a trundle of eight ſtaves or rounds, working in the cogs of the wheel; here it is plain, that the winch and trundle would make 10 revolutions for one of the wheel A B, and its axis D, on which the rope K winds in raiſing the weight W; and the winch being no longer than the ſum of the ſemidiameters of the great axle and rope, the trundle could have no more power on the wheel than a man could have by pulling it round by the edge, becauſe the winch would have no greater velocity than the edge of the wheel has, which we here ſuppoſe to be ten times as great as the velocity of the riſing weight; ſo that, in this caſe, the power gained would be

How power may be increaſed.

as

is 10 to 1. But if the length of the winch be 13 inches, the power gained will be as 20 to 1: if 19½ inches (which is long enough for any man to work by) the power gained will be as 30 to 1; that is, a man could raiſe 30 times as much by ſuch an engine as he could do by his natural ſtrength without it, becauſe the velocity of the handle of the winch would be 30 times as great as the velocity of the riſing weight; the abſolute force of any engine being in proportion of the velocity of the power, to the velocity of the weight raiſed by it. But then, juſt as much power or advantage as is gained by the engine, ſo much time is loſt in working it; which is common in all mechanical caſes whatever. Force of any engine.

In this ſort of machines it is requiſite to have a ratchet-wheel on the end of the axle C, with a catch to fall into its teeth; which will at any time ſupport the weight, and keep it from deſcending, if the perſon who turns the handle ſhould, through inadvertency or careleſſneſs, quit his hold while the weight is raiſing. Thus, by this means, the danger is prevented which might otherwiſe happen by the running down of the weight when left at liberty. Caution.

The third mechanical power or engine conſiſts either of one moveable pulley, or a ſyſtem of pullies; ſome in a block or caſe which is fixed, and others in a block which is moveable, and riſes with the weight. For though a ſingle pulley that only turns on its axis, and moves not out of its place, may ſerve to change the direction of the power, yet it can give no mechanical advantage thereto; but is only as the beam of a balance, whoſe arms are of equal length and weight. Thus, A is a ſingle pul- The pulley, Fig. 8.

ley, and if it ſupport the equal weights P and W, the cord BB to which they are appended, is equally ſtretched throughout, and the pulley A ſuſtains both the weights, or is drawn with a force equal to twice P. It is properly but another form of the balance.

Fig. 9. Three moveable pullies.

A combination of three moveable pullies A, B, C, connected by three diſtinct cords, each faſtened at one end to an immoveable block above. The power of the whole is diſcovered by ſuppoſing two ſuch weights, P and W, ſuſpended as will keep the machine in equilibrium, and then beginning with the leaſt weight or power P, and conſidering what force each ſeparate pulley ſuſtains. Thus, if P be one pound, the cord which ſuſtains it acts at its other end upon the fixed block above, and is conſequently re-acted upon by a force equal to one pound; and the pulley A, as in Fig. 8, is drawn with a force equal to two pounds.

By tracing the ſecond cord in the ſame manner, it will appear that the pulley B is drawn with twice the force of A, or four pounds; and C is drawn with twice the force of B, or 8 pounds. So that the purchaſe of this machine is ſuch, that the weight W has 8 times the power of P.

Velocity and power as 8 to 1.

The velocity of the weight to that of the power is (in a ſimilar way of arguing) thus: if P deſcend 8 inches, A will aſcend 4; B, 2; and C, or W, 1 inch; ſo that the velocities are reciprocally as the power and weight.

Fig. 10.

Another combination of pullies, whereof two, A and B, run in the fixed block X; and two others, C and D, in a moveable block, which raiſe the weight W, by pulling

ling the cord at P, which goes ſucceſſively over the pullies A, D, B, C, and is faſtened to the fixed blocks. The purchaſe of this machine is known by conſidering that the cord is equally ſtretched throughout, by putting two ſuch weights, P and W, as will counterpoiſe each other: for P is ſuſtained by the ſingle cord, and W by four folds of the ſame, viz. by the parts o, s, u, k; ſo that if P be one pound, W will be four pounds. Four moveable pullies.

The velocity of the power is to that of the weight as four to one: for if P deſcend four inches, the parts of the cord at k will aſcend towards e four inches, and all the other parts of the cord, from the pulley C, will equally follow each other, and C or W will aſcend one inch towards s; or the four parts of the cord o, s, u, k, will each be ſhortened one inch. Velocity as 4 to 1.

In like manner may the purchaſe of any other combination of pullies be determined: and it will always happen, that the *momenta* of the weight and power will be equal, as in the other mechanical powers. That is, if any power will raiſe one pound with a certain velocity, it will raiſe two pounds with half that velocity, or one hundred pounds with one hundredth part of that velocity, &c.

But as a ſyſtem of pullies has no great weight, and lies in a ſmall compaſs, it is eaſily carried about; and can be applied, in a great many caſes, for raiſing weights, where other engines cannot; but they have a great deal of friction, on three accounts—1. Becauſe the diameters of their axis bear a very conſiderable proportion to their own diameters. 2. Becauſe in working, they are apt to rub againſt one another, or againſt the ſides of the blocks.

3. Becauſe of the ſtiffneſs of the ropes that paſs over and under them.

The inclined plane.

The fourth mechanical power is the inclined plane; and the advantage gained by it is as great as its length exceeds its perpendicular height. Let A B be a plane parallel to the horizon, and C D a plane inclined to it; and ſuppoſe the whole length C D to be three times as great as the perpendicular height G f F. In this caſe the cylinder E will be ſupported upon the plane C D, and kept from rolling down upon it, by a power equal to a third part of the weight of the cylinder. Therefore, a weight may be rolled up this inclined plane with a third part of the power which would be ſufficient to draw it up by the ſide of an upright wall. If the plane was four times as long as it is high, a fourth part of the power would be ſufficient; and ſo on in proportion. Suppoſe a man has occaſion to ſet a weight upon an eminence, and the weight is ſo great that he cannot lift it by his natural ſtrength, he will take a long ſtout plank, or ſomething equivalent thereto, and ſetting it ſloping, will puſh the weight before him up the plank, to the place deſigned to ſet it in; and ſuch plank, or other contrivance like it, is an inclined plane. Now it is evident, that the ſhorter this inclined plane is, the ſteeper is the aſcent; and the longer the plane is, the aſcent muſt be the eaſier. Iti s plain alſo, that it is much eaſier to puſh a rolling weight up a hill that riſes gently, than up a hill which is very ſteep; which is univerſally known.

Fig. 11.

The force wherewith a rolling body deſcends upon an inclined plane, is to the force of its abſolute gravity, by which it would deſcend perpendicularly in a free ſpace, as the height of the plane is to its length. For, ſuppoſe the plane A B to be parallel to the horizon, the cylinder will

Fig. 12.

will keep at reſt on any part of a plane where it is laid. Fig. 13. If the plane be ſo elevated, that its perpendicular height from D is equal to half its length A B, the cylinder C will roll down upon the plane with a force equal to half its weight; for it would require a power (acting in the direction of A B) equal to half its weight to keep it from rolling. If the plane D B be elevated, ſo as to be perpendicular to the horizon, the cylinder C would deſcend with its whole force of gravity, becauſe the plane contributes nothing to its ſupport or hindrance; and therefore it would require a power equal to its whole weight to keep it from deſcending. To the inclined plane may be reduced all hatchets, chiſels, and other edge tools, which are chamfered only on one ſide. Fig. 14.

The fifth mechanical power or machine is the wedge; which may be conſidered as two equally inclined planes, D E F and C E F, joined together at their baſes e E F O: — then D C is the whole thickneſs of the wedge at its back A B C D, where the power is applied; E F is the depth or heighth of the wedge; D F, the length of one of its ſides, equal to C F, the length of the other ſide; and O F is its ſharp edge, which is entered into the wood intended to be ſplit, by the force of a hammer or mallet ſtriking perpendicularly on its back. Thus, A B is a wedge driven into the cleft C E D of the wood F G. The wedge, Fig. 15. Fig. 16.

When the wood does not cleave at any diſtance before the wedge, there will be an equilibrium between the power impelling the wedge downward and the reſiſtance of the wood acting againſt the two ſides of the wedge; when the power is to the reſiſtance as half the thickneſs of the wedge at its back is to the length of either of its ſides; becauſe the reſiſtance then acts perpendicular to the

the ſides of the wedge. But, when the reſiſtance on each ſide acts parallel to the back, the power that balances the reſiſtances on both ſides will be as the length of the whole back of the wedge is to double its perpendicular height.

When the wood cleaves at any diſtance before the wedge (as it generally does) the power impelling the wedge will not be to the reſiſtance of the wood as the length on the back of the wedge is to the length of both its ſides; but as half the length of the back is to the length of either ſide of the cleft, eſtimated from the top or acting part of the wedge. For, if we ſuppoſe the wedge to be lengthened down from the top C D, to the bottom of the cleft at E, the ſame proportion will hold; namely, that the power will be to the reſiſtance as half the length of the back of the wedge is to the length of either of its ſides: or, which amounts to the ſame thing, as the whole length of the back is to the length of both the ſides.

The wedge is a very great mechanical power, ſince not only wood but even rocks can be ſplit by it: which would be impoſſible to effect by the lever, wheel and axle, or pulley: for the force of the blow, or ſtroke, ſhakes the cohering parts, and thereby makes them ſeparate more eaſily.

rew. The ſixth and laſt mechanical power is the ſcrew; which cannot properly be called a ſimple machine, becauſe it is never uſed without the application of a lever or winch to aſſiſt in turning it; and then it becomes a compound engine of a very great force, either in preſſing the parts of bodies cloſer together, or in raiſing great weights. It may be conceived to be made by cutting a piece of paper, A B C, into the form of an inclined plane

or

or half wedge, and then wrapping it round a cylinder (Fig. 18.) it being evident that the winch muſt turn the cylinder once round, before the weight of reſiſtance can be moved from one ſpiral winding to another, as from d to c: therefore, as much as the circumference of a circle deſcribed by the handle of the winch is greater than the interval or diſtance between the ſpirals, ſo much is the force of the ſcrew. Thus, ſuppoſing the diſtance of the ſpirals to be half an inch, and the length of the winch twelve inches, the circle deſcribed by the handle of the winch where the power acts, will be 76 inches nearly, or about 152 half inches; and conſequently 152 times as great as the diſtance between the ſpirals: and therefore a power at the handle, whoſe intenſity is equal to no more than a ſingle pound, will balance 152 pounds acting againſt the ſcrew; and as much additional force as is ſufficient to overcome the friction, will raiſe the 152 pounds; and the velocity of the power will be to the velocity of the weight as 152 to 1. Hence it appears, that the longer the winch is, and the nearer the ſpirals are to one another, ſo much the greater is the force of the ſcrew. Fig. 18.

A machine for ſhewing the force or power of the ſcrew may be contrived in the following manner:—Let the wheel C have a ſcrew a b on its axis, working in the teeth of the wheel D, which ſuppoſe to be 48 in number. It is plain, that for every time the wheel C and ſcrew a b are turned round by the winch A, the wheel D will be moved one tooth by the ſcrew; and therefore, in 48 revolutions of the winch, the wheel D will be turned once round. Then, if the circumference of a circle, deſcribed by the handle of the winch A, be equal to the circumference of a groove e round the wheel D, the velocity of the handle will be 48 times as great Fig. 19.

as

as the velocity of any given point in the groove. Conſequently, if a line G goes round the grove e, and has a weight of 48 pounds hung to it below the pedeſtal E F, a power equal to 1 pound at the handle will balance and ſupport the weight. To prove this by experiment, let the circumferences of the grooves of the wheels C and D be equal to one another; and then if a weight H, of one pound, be ſuſpended by a line going round the groove of the wheel C, it will balance a weight of 48 pounds hanging by the line G; and a ſmall addition to the weight H will cauſe it to deſcend, and ſo raiſe up the other weight.

Experiment

If a line G, inſtead of going round the groove e of the wheel D, goes round its axle I, the power of the machine will be as much increaſed as the circumference of the groove e exceeds the circumference of the axle: which ſuppoſing it to be ſix times, then 1 pound at H will balance 6 times 48, or 288 pounds, hung to the line on the axle: and hence the power or advantage of this machine will be as 288 to 1. That is to ſay, a man, who by his natural ſtrength could lift an hundred weight, will be able to raiſe 288 by this engine. If a ſyſtem of pullies were applied to the cord H, the power would be increaſed to an amazing exceſs; but it would be here as in all other mechanical caſes; for the time loſt is always as much as the power gained, becauſe the velocity with which the power moves, will ever exceed the velocity with which the weight riſes, as much as the intenſity of the weight exceeds the intenſity of the power.

Friction.

The friction of the ſcrew is very conſiderable; and there are few compound engines but what, on account of the friction of the parts againſt one another, will require a third part more of the power to work them when loaded, than

than what is ſufficient to conſtitute a balance between the weight and the power.

In the lever, the friction is nothing. In the wheel and axle, it is as ſmall as the diameter of the gudgeons (added to the power required to bend the rope) is leſs than the diameter of the wheel; but it increaſes according to the weight with which the axle is charged. The like might be ſaid of the pullies, if they did not rub againſt one another, or againſt the ſides of the mortiſes in the block where they are placed. A new rope of 1 inch diameter going over a pulley 3 inches diameter, and pulled with a force equal to 5 pounds, requires a force of 1 pound or upwards to bend it; and a rope 2 inches diameter requires 4 times as much force.

Wood greaſed, or metal oiled, have nearly the ſame friction; and the ſmoother they are, their friction is the leſs. Yet metals may be ſo highly poliſhed, as to have their friction increaſed by the coheſion of their parts.

Wood ſlides eaſier upon the ground in wet weather than in dry; and eaſier than an equal weight of iron in dry weather: but iron ſlides eaſier than wood in wet weather. Iron or ſteel running in braſs, has the leaſt friction of any. Lead makes a great deal of reſiſtance. In wood, acting upon wood, greaſe makes the motion at leaſt twice as eaſy. Wheel-naves, greaſed or tarred, go four times as eaſy as when wet. Smooth ſoft wood, moving upon ſmooth ſoft wood, has a friction equal to about a third part of the weight. In rough wood, the friction is almoſt equal to half the weight. In ſoft

wood upon hard, or hard upon ſoft, the friction is equal to about a fifth part of the weight.

In poliſhed ſteel, moving upon poliſhed ſteel or pewter, the friction is about a fourth part of the weight; on copper, a fifth part; and on braſs, a ſixth part of the weight. Metals of the ſame ſort have more friction than different ſorts.

In general, the friction increaſes in the ſame proportion with the weight. The friction is alſo greater with a greater velocity; but not ſo great in proportion as the increaſe of velocity.

To have the friction of machines as little as poſſible, they ought to be made of the feweſt and ſimpleſt parts. The diameters of the wheels and pullies ought to be large, and the gudgeons of the axles as ſmall as can be conſiſtent with the required ſtrength. The ſides of the pullies ought not to be all over flat, but to have a ſmall riſing in the middle, to keep them from rubbing againſt each other's ſides, and againſt the ſides of their mortiſes at a diſtance from their axle. All the cords and ropes ought to be as pliant as poſſible; and, for that end, rubbed with greaſe. The teeth of the wheels ſhould juſt fit and fill the openings, ſo as not to be ſqueezed nor ſhaken therein. All the parts which work into, or upon one another, ought to be ſmooth; the gudgeons ought juſt to fit their holes, and the working parts muſt be greaſed. The rounds or ſtaves of the trundles may be made to turn about upon iron ſpindles, fixed in the round end-boards; which will take off a great deal of friction.

Let

Let the ſtrength of all parts be in proportion to the ſtreſs they are to bear, ſo as they may laſt equally well. He is by no means a perfect mechanic who only adjuſts the ſtrength to the ſtreſs, if he does not contrive all the parts to laſt ſo, as that one ſhall not fail before another.

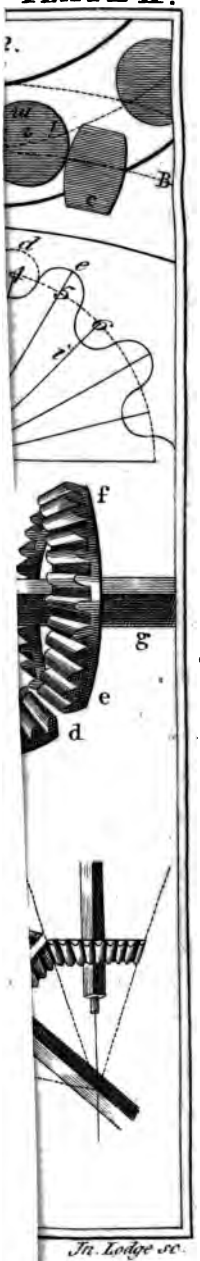
When any motion is to be long continued, contrive the machine ſo, as that the working power may always move to act one way, if it can be done: for this is better and eaſier performed than when the motion is interrupted by the power's being forced to move firſt one way and then another; becauſe every new change of motion requires a new additional force to effect it; and a body in motion cannot ſuddenly receive a contrary motion without great violence, and danger of tearing the machine to pieces. But when the nature of the thing requires that a motion ſhould ſuddenly be communicated to a body, or ſuddenly ſtopt, let the force act againſt ſome ſpring, to prevent the machine's being damaged by a ſudden jolt.

When a machine is moved by two handles, or winches on the ends of an axle, the handles are ſo placed as that when the one is up, the other is down; which is the worſt way poſſible of placing them, ſave that of their being both up or down together. For, when a man raiſes a weight by means of turning a winch, he loſes half his force when the winch is upward; becauſe he puſhes himſelf as much backward as he puſhes the winch forward; and when the handle of the winch is down, directly below the axle, he loſes half his force; becauſe the winch pulls him as much toward it as he pulls it toward him: and, therefore, the greateſt effect of his force on the machine is when he either pulls the winch upward, on the ſide of the axle next to him, or puſhes it

downward, on the ſide fartheſt from him. Yet, even in theſe caſes, the pulling force is ſtronger than the puſhing.

In order to remedy this defect as much as poſſible, the handles ſhould be ſo placed as to ſtand at right angles to one another; and then, where there is a man at each handle, the effect of the one man's force will be greateſt when the effect of the other man's is leaſt upon the machine. Whereas, in the common way of placing theſe handles, when the effect of one man's force is the greateſt, the other man's is ſo too; and when the effect of that man's force is the leaſt, ſo alſo is the other's; which is working at the greateſt diſadvantage poſſible.

PLATE II.



MILL-WORK.

In the Conſtruction of Water Mills, it will be neceſſary to obſerve the following Rules.

MEASURE the perpendicular height of the fall of water, in feet, above that part of the wheel on which the water begins to act, and call that the height of the fall.

II. Multiply this conſtant number 64,2882 by the height of the fall in feet, and the ſquare root of the product ſhall be the velocity of the water at the bottom of the fall, or the number of feet that the water there moves per ſecond.

III. Divide the velocity of the water by three, and the quotient ſhall be the velocity of the float-boards of the wheel, or the number of feet they muſt each go thro' in a ſecond, when the water acts upon them ſo as to have the greateſt power to turn the mill.

IV. Divide the circumference of the wheel in feet by the velocity of its floats in feet per ſecond, and the quotient ſhall be the number of ſeconds in which the wheel turns round.

V. By

V. By this laſt number of ſeconds divide 60, and the quotient ſhall be the number of turns of the wheel in a minute.

VI. Divide 120 (the number of revolutions a millſtone 4½ feet diameter ought to have in a minute) by the number of turns of the wheel in a minute, and the quotient ſhall be the number of turns the millſtone ought to have for one turn of the wheel.

VII. Then, as the number of turns of the wheel in a minute is to the number of turns of the millſtone in a minute, ſo muſt the number of ſtaves in the trundle be to the number of cogs in the wheel, in the neareſt whole numbers that can be found.

By theſe rules the following table is calculated to a water wheel 18 feet diameter; which, I apprehend, may be a good ſize in general.

To aſcertain the force or power of any moderate ſtream of water, let the ſame be obſtructed by a dam acroſs the ſtream, ſo as to force all the water through a trough or open ſpout into a large veſſel or reſervoir, by meaſuring ſo much water as ſhall be received as above, in any given time, viz. a ſecond, minute, &c.; and multiplying the ſame by the number of ſeconds or minutes in an hour, the whole force or impulſe of ſuch ſtream of water per hour at any given height, may be readily aſcertained in rivers too large to be meaſured as above, the force or impulſe may be calculated from the ſpace that a ſtraw floating upon the ſurface of the water, in any given time, and at a medium depth and width of the river, will deſcribe.

The

The Mill-Wright's Table.

Height of the fall of water.	Velocity of the fall of water per second.		Velocity of the wheel per second.		Revolutions of the wheel per minute.		Revolution of the millstone for one of the wheel.		Cogs in the wheel, and staves in the trundle.		Revolutions of the millstone per minute by these staves and cogs.	
Feet.	Feet.	100 parts of a foot.	Feet.	100 parts of a foot.	Revolutions.	100 parts of a rev.	Revolutions.	100 parts of a rev.	Cogs.	Staves.	Revolutions.	100 parts of a rev.
1	8	02	2	67	2	83	42	40	254	6	119	84
2	11	34	3	78	4	00	30	00	240	7	120	00
3	13	89	4	63	4	91	24	44	196	8	120	28
4	16	04	5	35	5	67	21	16	190	9	119	74
5	17	93	5	98	6	34	18	92	170	9	119	68
6	19	64	6	55	6	94	17	28	156	9	120	20
7	21	21	7	07	7	50	16	00	144	9	120	00
8	22	68	7	56	8	02	14	96	134	9	119	34
9	24	05	8	02	8	51	14	10	140	10	119	14
10	25	35	8	45	8	97	13	38	134	10	120	18
11	26	59	8	86	9	40	12	76	128	10	120	32
12	27	77	9	26	9	82	12	22	122	10	119	80
13	28	91	9	64	10	22	11	74	118	10	120	36
14	30	00	10	00	10	60	11	32	112	10	118	72
15	31	05	10	35	10	99	10	92	110	10	120	96
16	32	07	10	09	11	34	10	58	106	10	120	20
17	33	06	11	02	11	70	10	36	102	10	119	34
18	34	02	11	34	12	02	9	98	100	10	120	20
19	34	95	11	65	12	37	9	70	98	10	121	22
20	35	86	11	95	12	68	9	46	94	10	119	18
1	2		3		4		5		6		7	

To conſtruct a mill by this table, find the height of the fall of water in the firſt column, and againſt that height in the ſixth column, you have the number of cogs in the wheel, and ſtaves in the trundle, for cauſing the mill-ſtone 4 feet 6 inches diameter, to make about 120 revolutions in a minute, as near as poſſible, when the wheel goes with one third part of the velocity of the water. And it appears by the 7th column, that the number of cogs in the wheel, and ſtaves in the trundle, are ſo near the truth for the required purpoſe, that the leaſt number of revolutions of the millſtone in a minute is 118, and the greateſt number never exceeds 121; which is according to the ſpeed of ſome of the beſt mills I have yet ſeen.

A leſs quantity of water will turn an overſhot than what will turn an underſhot or breaſt wheel; as an overſhot is actuated by the ſtatical weight, or gravity, and the underſhot or breaſt by impulſe only; ſo that where there is but a ſmall quantity of water, and a fall great enough for the wheel to lie under it, the overſhot wheel is always uſed. But where there is a large body of water, and little fall, the underſhot wheel muſt take place. Where the water runs only upon a little declivity, it can act but ſlowly upon the under part of the wheel; in which caſe, the motion of the wheel will be very ſlow: and therefore, the float-boards ought to be very long, though not high, that a large body of water may act upon them; ſo that what is wanting in velocity, may be made up in power; and then the cog-wheel may have a greater number of cogs, in proportion to the rounds in the trundle, in order to give the millſtone a ſufficient degree of velocity.

The Method for ſetting out a Spur Wheel and Wallower.

DRAW the pitch lines A 1, B 1, A 2, 2 B; then divide them into the number of teeth or cogs required, as a b c. Plate II. Fig. 1.

Divide one of thoſe diſtances, as b c, into ſeven equal parts, as 1, 2, 3, 4, 5, 6, 7; three parts allow for the thickneſs of the cogs, as 1, 2, 3 in the cog a, and four for the thickneſs of the ſtave of the wallower (one reaſon for allowing three parts for the cog, and four for the ſtave is, the wallower is in general of leſs diameter than the wheel, therefore ſubject to more wear in proportion of the number of cogs to the number of ſtaves; but if there is the ſame number of ſtaves as of cogs, they may be of equal thickneſs) as 1, 2, 3, 4 in the ſtave m, Fig. 2; the height of the cog is equal to four parts; then divide its height into five equal parts, as 1, 2, 3, 4, 5 in the cog C; allow three for the bottom to the pitch line of the cog; the other two parts for epicycloid, ſo as to fit and bear on the ſtave equally. The millwrights in general put the point of a pair of compaſſes in the dot 3 of the cog a, and ſtrike the line d, e; then remove the point of the compaſſes to the point d, and ſtrike the curve line 3 f, which they account near enough the figure of the epicycloid.

The method for a face wheel is thus: Divide the pitch line A B into the number of cogs intended, as a b c; divide the diſtance b c, into ſeven equal parts; three of thoſe parts allow for the thickneſs of the cogs, as 1, 2, 3 in the cog a, four for the height, and four for the width, as d e, and four for the thickneſs of the ſtave m; draw a Fig. 2.

line through the center of the cog, as the line A I, at S; and on the point 5, deſcribe the line d e; remove the compaſſes to the point A, and draw the line f g, which forms the ſhape of the cog; then ſhape the cog on the ſides to a cycloid, as d e f g, Fig. 1. But this method of ſetting out the ſhape of a cog is variable, according to the cycloid in different diameters of wheels.

Spur Nuts. Fig. 3. In common ſpur nuts, divide the pitch line A, into twice as many equal parts as you intend teeth, as a, b, c, d, e; with a pair of compaſſes opened to half the diſtance of any of thoſe diviſions, from the points a 1, c 3, e 5, draw the ſemicircles a, c, and e, which will form the ends of the teeth. From the points 2, 4, and 6, draw the ſemicircles g h i, which will form the hollow curves for the ſpaces; but if the ends of the teeth were epicycloids, inſtead of ſemicircles, they would act much better.

The Principal of Bevel Geer

Bevel Geer. Fig. 4. CONSISTS in two cones rolling on the ſurface of each other, as the cone A and B revolving on their centers a b, a c; if their baſes are equal, they will perform their revolutions in one and the ſame time, or any other two points equally diſtant from the center a, as d 1, d 2, d 3, &c. will revolve in the ſame time as f 1, f 2, f 3, &c. In the like manner, if the cones a d e be twice the diameters at the baſe d e, as the cones a f e are, then if they turn about their centers when the cone a f d has made one revolution, the cone a d e will have made but half a revolution; or when a f e has made two revolutions, a d e will have made but one, and every part equally diſtant from the center a, as f 1, f 2, f 3, &c.

Fig. 5. and 6.

&c. will have made two revolutions to e 1, e 2, e 3, &c. and if the cones were fluted, or had teeth cut in them, diverging from the center a to the baſes d c, e f, Fig. 7 and 8. they would then become bevel geer. The teeth at the point of the cone being ſmall and of little uſe, may be cut off at E and F, Fig. 8, as ſeen by Fig. 9, where the Fig. 8 & 9. upright ſhaft, a b, with the bevel wheel, c d, turns the bevel wheel e f with its ſhaft b g, and the teeth work freely into each other, as a b, Fig. 10. The teeth may Fig. 10. be made of any dimenſion, according to the ſtrength required; and this method will enable them to overcome a much greater reſiſtance, and work ſmoother than a face wheel and wallower of the common form can poſſibly do; beſides, it is of great uſe to convey a motion in any direction, or to any part of a building, with the leaſt trouble and friction.

The method of conveying motion in any direction, and proportioning or ſharping the wheels thereto, is as follows: Let the line a b repreſent a ſhaft coming from a wheel; draw the line c d to interſect the line a b, in Fig. 11. the direction that the motion to be conveyed is intended, which will now repreſent a ſhaft to the intended motion.

Again, ſuppoſe the ſhaft c d is to revolve three times, whilſt the ſhaft a b revolves once, draw the parallel line i i, at any diſtance not too great (ſuppoſe 1 foot by a ſcale) then draw the parallel line k k at 3 feet diſtance, after which, draw the dotted line w x, through the interſection of the ſhafts a b and c d, and likewiſe through the interſection of the parallel lines ii and k k, in the points x and y; which will be the pitch line of the two bevel wheels, or the line where the teeth of the two

Fig. 12. two wheels act on each other, as may be ſeen Fig. 12, where the motion may be conveyed in any direction.

Fig. 13. The univerſal joint, as repreſented Fig. 13, may be applied to communicate motion inſtead of bevel geer, where the ſpeed is to be continued the ſame, and where the angle does not exceed 30 or 40 degrees, and the equality of motion is not regarded; for as it recedes from a right line, its motion becomes more irregular. This joint may be conſtructed by a croſs, as repreſented in the figure; or with four pins faſtened at right angles upon the circumference of a hoop, or ſolid ball. It is of great uſe in cotton mills, where the tumbling ſhafts are continued to a great diſtance from the moving power. But by applying this joint, the ſhafts may be cut into convenient lengths, by which it will be enabled to overcome greater reſiſtance.

To deſcribe the Cycloid and Epicycloid: of Uſe in Shaping the Teeth of Wheels, &c.

Fig. 14. IF a point or pencil a, on the circumference of the circle B, proceeds along the plane a C, in a right line, and at the ſame time revolves round its center, it will deſcribe a cycloid.

Fig. 15. And, if the generating circle D, moves along the circumference of another circle E, and at the ſame time turns round its center, the point o will deſcribe an epicycloid.

A Brief

A

Brief Hiſtory of Electricity.

THOUGH it is certain, ever ſince the creation of the world, the electric fluid had all the operations it has at preſent, yet the diſcovery of its action, and even of its exiſtence, is (comparatively ſpeaking) of a very late date. *Thales* the *Mileſian*, who lived 600 years before Chriſt, was the firſt who obſerved the electrical properties of amber. Of theſe, indeed, he knew no more than that this ſubſtance would attract light bodies when it was rubbed. For 300 years after his time, we hear nothing further concerning this ſubject. Theophraſtus then tells us, that the *Lyncuriam* (now called the *Tourmalin*) has the property of attracting light bodies, as well as amber. From this time there is a chaſm in the hiſtory of electricity for 1900 years. It was in the beginning of the 17th century that the ſubject of electricity became a diſtinct ſcience; and the foundation was laid of thoſe diſcoveries (which have ſince taken place) by Dr. William Gilbert, an Engliſh phyſician, who may juſtly be called the Father of Electricians. In the year 1600 he wrote a book, *De Magnette*, which contains a variety of electrical experiments. All theſe, however, conſidered only the attractive property of certain ſubſtances, which, from their agreement in this reſpect with amber, were called electric. Dr. Gilbert's merit conſiſts in his having been at great pains to find out a number of ſuch ſubſtances,

Electricity when firſt mentioned.

Diſcoveries of Dr. Gilbert.

ſtances, and thus conſiderably enlarge the number of electrics.

Mr. Boyle's improvements.

Till the year 1670, it does not appear that any farther diſcoveries were made, except ſome trifling additions to the catalogue of electrics. About this time Mr. Boyle applied himſelf to the ſtudy of electricity: he enlarged the catalogue of electrics, and found that their electric properties were increaſed by warming and wiping them before they were rubbed.

Diſcoveries of Otto Guericke.

Otto Guericke, however, who was cotemporary with Mr. Boyle, improved the ſcience much farther. He made uſe of a ſulphur globe, whirled on an axis, much like our preſent glaſs globes; by which means he excited a greater power of electricity than any of his predeceſſors, and tried all their experiments to much more advantage. He diſcovered the electric repulſion; and not only ſaw the electric light more clearly than Mr. Boyle, but heard the hiſſing ſound with which it is emitted. He alſo made another remarkable diſcovery, but which has ſince been very generally overlooked; viz. that a feather, when repelled by an excited electric, always keeps the ſame face towards the body which repels it, as the moon does to the earth.

Diſcovery by Sir Iſaac Newton.

The next diſcovery of any moment was made by Sir Iſaac Newton; who obſerved, that the electric attraction and repulſion penetrated through glaſs. In the

Mr. Hawkſbee's improvements

year 1709 a treatiſe was written on electricity by Mr. Hawkſbee; who not only far excelled all his predeceſſors and cotemporaries, but alſo made ſome diſcoveries which well deſerve the attention of the moſt expert electricians at this day. He was the firſt that applied

plied a glaſs globe to the machine; and he remarked various appearances of the electric light and the noiſe that accompanied it, together with a variety of phænomena relating to electric attraction and repulſion.

After his death, not only the uſe of glaſs globes, but even the ſtudy of electricity itſelf, ſeems to have been pretty generally laid aſide for ſome time. The reaſon of this was, that the recent diſcoveries of Sir Iſaac Newton engroſſed the attention of philoſophers to ſuch a degree, that they had no leiſure for any other purſuits. However, after the death of that great man, electricity began to revive, and in 1729 a capital diſcovery was made by Mr. Stephen Grey, who (by his curious obſervations) found out the difference between electrics and conductors; who, with the aſſiſtance of Mr. Wheeler, contributed much to the advancement of electricity. Soon after, Mr. Du Fay accidentally diſcovered the difference between poſitive and negative electricity, by obſerving that a piece of leaf gold repelled by an excited glaſs tube, was again eagerly attracted to it, after it had touched ſome body which was not an electric: the ſame was alſo the caſe with roſin, ſealing-wax, ſulphur, and a number of other ſubſtances.

Mr. Grey's diſcovery.

Mr. Du Fay's diſcovery.

It may be obſerved, that although the ſcience had, through the indefatigable attention of ſo many ingenious perſons, and by the diſcoveries that were daily produced, excited the curioſity of philoſophers, and engaged their attention; yet, as the cauſes of every thing, whether ſmall or great, are ſeldom much attended to if their effects are not particularly ſtriking and ſingular, ſo electricity had till the year 1746 been ſtudied by none but philoſophers, until that capital diſcovery

discovery of the vast accumulation of its power, in what is called the Leyden Phial, was accidently made by Mr. Muschenbroek in the year 1746; at which time the study of electricity became general, and gave more surprize, even to philosophers, than any other science whatsoever. From the time of this discovery, electricity became the general subject of conversation, and great numbers of people got their livelihood by going about and shewing its curious phænomena. It was also applied medically, and several persons found great benefit by it, particularly a paralytic person cured at Geneva; another of a violent pain in his head; also a woman of a disorder in her eyes at Bologna; so that from this time we may date the introduction of electricity into the medical art. It is impossible to enumerate all the happy effects which have been performed in curing various disorders incident to the human body by electrical applications.

Mr. Muschenbroek's experimental discovery.

Medical electricity first applied.

The science of electricity has since the above period been greatly improved by the indefatigable industry of the celebrated philosophers, Dr. Franklin and Dr. Priestley; but it would be endless to enumerate all the improvements that have been made by a great number of other gentlemen, who have each added something towards its advancement; but whoever would make himself acquainted with the particulars concerning those advances, should read over the elaborate history of electricity compiled by the learned Dr. Priestley: a work that will inform him of whatever had been done relative to the subject till its publication.

Of

Of the Electric Fluid.

THE earth and all the bodies we are acquainted with, are ſuppoſed to contain a certain quantity of an exceedingly elaſtic and ſubtle fluid, which philoſophers have agreed to term electric. This certain quality belonging to all bodies, may be called their natural ſhare; and ſo long as each body contains neither more nor leſs than this quantity, it ſeems to be wholly dormant, and produces no ſenſible effect; but the moment that the equilibrium is diſturbed, and any body becomes poſſeſſed of more or leſs than its natural quantity, very remarkable effects ariſe from it. The body is ſaid to be electrified, and is capable of exhibiting appearances which are aſcribed to the power of Electricity.

This equilibrium could never be diſturbed, or, if it was diſturbed, would be immediately reſtored, and therefore be inſenſible, but that ſome bodies do not admit the paſſage of this electric fluid through their pores, or along their ſurfaces, though others do. By this means, whenever any body has acquired an additional quantity of electric matter, and is everywhere ſurrounded with bodies through which it cannot paſs, it muſt remain overloaded; or, if it has loſt part of what naturally belonged to it, it muſt remain exhauſted; becauſe the ſurrounding bodies prevent any of the fluid from going to it, or coming out of it; and the body is then ſaid to be inſulated. Thoſe bodies through which the electric fluid can paſs, are called conductors; and thoſe through which it cannot paſs, are called non-conductors of electricity; and into theſe two kinds all bodies whatever are claſſed by electricians.

The beſt conductors of electricity, or thoſe which admit the electric fluid to paſs through them with the greateſt caſe, are metals of all kinds. And the moſt perfect of the non-conducting claſs of bodies are glaſs, roſin, ſealing-wax, ſulphur, bees-wax, and baked wood, among ſolids; and oils and air among fluids. But all ſubſtances become conductors when they are made very hot. They are alſo called electrics, and the conducting ſubſtances are called non-electrics.

The method of diſturbing the equilibrium of the electric fluid in bodies, or of making it paſs from one to another, is chiefly friction, or a ſlight rubbing of them, one againſt another. In this caſe, the electric fluid will in general leave that ſubſtance which has the rougher ſurface, and paſs upon the other, which is ſmoother; or it will leave that ſubſtance which is the leſs perfect electric, and paſs upon the other, which is the more perfect electric of the two. Thus, if I take a ſmooth glaſs tube (ſuch as is repreſented) and draw it through my hand, the effect of that friction is that the electric matter leaves my hand, and paſſes upon the glaſs, where it will remain as an addition to its natural quantity. For as neither the glaſs, nor the air which ſurrounds it, are conductors of electricity, this redundancy of the electric matter cannot poſſibly get away; but if my finger, a piece of metal, or any conducting ſubſtance, be preſented to any part of the glaſs thus overloaded with the electric fluid, it will paſs immediately from that part into them; and if they be preſented to every part of the tube ſucceſſively, the whole of this redundant electricity will be diſcharged, and every thing will become juſt as it was before the operation. The glaſs, in this caſe, is ſaid to be excited, becauſe the friction ſeems to excite

Plate III. Fig. 1.

PLATE III.

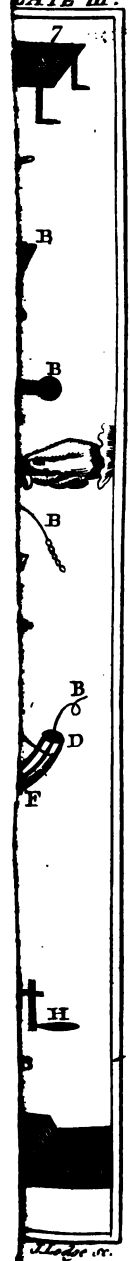


Plate I
Fig. 1.

excite, or call upon the electric power which it had before, but which lay dormant in it.

In like manner, when the globe is whirled in the electrical machine, the friction of the glaſs againſt the rubber makes the electric fluid which was in the rubber paſs on the glaſs, from whence it is conveyed to the prime conductor, the points of which are preſented to every part of the globe in ſucceſſion: and as the friction is continued, there will, by this means, be a conſtant ſupply of the electric matter to the prime conductor, though other bodies be preſented to it, and keep diſcharging it all the while in viſible ſparks. The hand, in the former of theſe caſes, and the rubber in the latter, which had parted with their ſhare of the electric fluid to the glaſs, againſt which they were rubbed, receive an immediate ſupply from the conducting ſubſtances in contact with them; and theſe are again ſupplied by the general maſs of the fluid that is lodged in the earth.

On the contrary, if I draw through my hand a ſtick of ſealing-wax, a piece of ſulphur, or a tube of rough glaſs, the effect of the friction is, that a quantity of electric matter naturally belonging to the ſulphur, &c. paſſes from it to my hand; and the ſulphur being ſurrounded by the air, which is a non-conductor, remains exhauſted, and is ready to take ſparks of electric fire from any bodies that are preſented to it. But it is impoſſible to diſtinguiſh by the eye which way the electric matter paſſes, its velocity is ſo extremely great. The ſulphur in this caſe, though deprived of its ſhare of electricity, is ſaid to be excited as well as the glaſs which was overloaded with it, becauſe, though the ſtate they are in be the reverſe of one another, the effects produced by them

are, in many reſpects, ſimilar. The appearances which lead us to diſtinguiſh them, will be mentioned hereafter.

Of Electrical Attraction and Repulſion.

THE great laws of the electric fluid, and thoſe on which all the phenomena of electricity depend, are, that it is in a much higher degree than air elaſtic, and repulſive of itſelf; that two bodies having both of them either more or leſs than their natural ſhare of it, repel one another; but that if one of them have more, and the other leſs than its ſhare, they will attract one another.

Thus: If I hang a bundle of hairs or feathers upon the prime conductor, the moment I electrify them, by turning the wheel of the machine, they begin to fly from one another; ſo that ſome of them will ſtand quite erect, in a beautiful manner; and they cannot be made to collapſe and be brought in contact with one another till I diſcharge the conductor, by taking a ſpark from it with a piece of metal, or ſome other conducting ſubſtance. A large plumy feather alſo grows beautifully turgid when it is electrified, expanding its fibres in all directions; and they collapſe when the electricity is taken off.

If I hold in my hand a bundle of threads, hairs, or feathers, and preſent them to the electrified conductor, the electric fluid with which the conductor is overloaded, repels the electric fluid from thoſe parts of the threads, &c. which are next to it, into the more diſtant parts of thoſe bodies, or into my hand, and ſo into the ground;

ground; the conſequence of which is, that the threads having leſs than their natural ſhare, do ſtrongly repel and avoid one another, and at the ſame time are ſtrongly attracted by the conductor, which is in an oppoſite ſtate. If the conductor had been deprived of its natural ſhare of electricity, the bodies preſented to it would have had more than their natural ſhare; ſo that ſtill the ſame appearance of mutual repulſion, and of attraction by the conductor, would have taken place; and univerſally all bodies that are brought within the influence of electrified bodies, whether they are ſo by having more or leſs than their natural ſhare of the electric fluid, become poſſeſſed of a contrary electricity. For the ſame reaſon, excited electrics of every kind attract all light bodies which are brought within the ſphere of their influence.

Electrical attraction and repulſion are exhibited in a very pleaſing manner, by means of a glaſs tube and a feather. When the tube is excited, by being drawn through the hand, or a rubber, the feather when brought near it, will be attracted and jump to the tube; then, after taking ſome time to get fully ſaturated with electric matter (becauſe, being a bad conductor, it can receive it but very ſlowly) it will ſuddenly jump from it, and fly towards the next conductor, upon which it may diſcharge the redundant electricity it has acquired. If no other body happen to be in the way, it will tend towards the ground; but if the electrified tube be held under it, it will ſtill be repelled, and driven into the middle of the room, where it may be kept ſuſpended, or be driven about in all directions almoſt as long as a perſon pleaſes, if the air be dry. Experiment

Other beautiful effects of electrical attraction and repulſion are ſhewn at the prime conductor belonging to the

Fig. 3. the machine. Suſpend a plate of metal from the conductor, which is ſupported by two pillars of glaſs, and muſt be ſuppoſed to be ſupplied with electricity from the globe; and underneath it, at the diſtance of about three or four inches, put another plate of the ſame ſize: upon the lower of theſe plates lay a feather, or a ſmall ſlip of light paper; and, as ſoon as the wheel begins to turn, the feather or the paper will be attracted, and jump to the upper plate F; from which it will be immediately repelled, and fly to diſcharge itſelf upon the lower plate P, which is ſupported on the pedeſtal H G; after which it will be ready to be attracted and repelled again. Thus will the feather or paper fly from the one plate to the other alternately, and with inconceiveable rapidity, if the electrification be pretty vigorous. When the pieces of paper are cut into the figures of men and women, they exhibit a kind of dance, which is extremely amuſing.

Electrical bells. Fig. 5. This experiment will be the more diverting if it be accompanied with that of the electrical bells, which depends upon the ſame principle. Four bells, a, b, c, d, hang from braſs rods, communicated with the prime conductor, and another bell, e, fixed on a braſs pedeſtal A, reaching to the ground; and four ſmall braſs balls, ſuſpended by ſilken threads, hang between a b, c, d, and the bell e in the middle. The conſequence of this diſpoſition is, that the outermoſt bells, which hang from the prime conductor by braſs chains, are electrified, and attract the braſs balls which hang by ſilk; and the attraction being vigorous, they are made to ſtrike the bells with ſome force, and make them ring. Being then loaded with electricity, they are immediately repelled from theſe outermoſt bells, and fly to unload themſelves by

by ſtriking upon the middle bell, which is inſulated by the glaſs pillar B, upon the pedeſtal A; and from which the electric matter paſſes to the floor by means of the braſs pedeſtal A. The braſs balls, which now may be called clappers to the bells, are then ready to be attracted by the outermoſt bells, as at firſt; and thus the ringing may be continued as long as it is agreeable. The amuſement will be heightened, if the electrician now and then touch the prime conductor with a braſs rod, or with his finger; for then the dancing and ringing will ceaſe, and will not be renewed till his finger or the rod be removed. If he conceals this application of his finger, or the rod, with a little art, the figures will ſeem to dance, and the bells to ring, at the word of command.

Of the Electric Spark.

WHEN I preſent a piece of metal, or any other good conducting ſubſtance, to the overloaded prime conductor, the electric matter will paſs with violence from the one to the other; an electric ſpark, with the appearance of fire, will be ſeen darting between them, and a report which is uſually compared to a ſnapping noiſe, will be heard. If the piece of metal that is preſented to the prime conductor be inſulated, ſo that it cannot immediately loſe what it receives, it will only take part of the charge from the prime conductor (the whole of the redundant electricity being divided between them in proportion to their ſurfaces) and either of them will give a ſmaller ſpark to another body that is preſented to them.

When any perſon ſtands upon the ſtool with feet made of glaſs, or baked wood (ſuch as is repreſented) and takes Fig. 7.

in

in his hand a chain faſtened to the prime conductor; being then inſulated, he may be conſidered as a part of the prime conductor; and any part of his body will exhibit all the ſame appearances which the prime conductor itſelf will do. Thus, if the finger of any perſon ſtanding upon the floor be preſented to him, a ſpark of fire will ſeem to iſſue from him, and both he and the perſon that receives it will feel a painful ſenſation, like a pricking; and the ſame ſnapping noiſe above mentioned will be heard. Every part of his body will then attract light ſubſtances: and the bits of feathers, or the human figures above mentioned, cut in paper, and laid on a plate, will perform the ſame dances that were mentioned before, if the palm of his hand be expanded over them. Alſo the hairs of his head, or of his wig, if they happen to be looſe, will repel one another; and many of them will ſtand upright. As theſe electric ſparks, which are attended with a ſenſation moderately painful, will be excited wherever he is touched, or wherever he touches any other perſon, this experiment will thereby furniſh very great diverſion.

Subſtances ſet on fire by electricity.

The electric ſpark has not only the appearance of fire, but is capable of actually ſetting fire to various ſubſtances that are eaſily inflamed; but the inflammation is probably produced by the rapid motion into which the parts of the ſubſtances are thrown, by the action of the electric matter upon them. Thus, if ſpirits of wine be held in a ſpoon, and an electric ſpark be drawn from the ſpoon, ſo as to paſs through any part of the ſpirits, they will catch fire, and burn as if they had been lighted by a candle. The ſpoon in which the ſpirits are contained may either be connected by the prime conductor, and the

ſpark

ſpark drawn through them by a perſon ſtanding on the floor; or the ſpoon may be held by a perſon ſtanding on the floor, and the ſpark be drawn through them by a braſs rod, either connected immediately with the prime conductor, or held in the hand of a perſon ſtanding on the ſtool, in the manner mentioned above. If a candle be blown out, and an electric ſpark be immediately drawn through the ſmoke, it will often be lighted again; but it requires a pretty ſtrong ſpark, and ſome degree of dexterity and experience in the operator, to produce this effect with certainty. It will be more amuſing, and the effect will be as certain, if the ſpark be drawn through the ſpirits by the end of a perſon's finger.

Not only are the ſenſes of feeling, ſeeing, and hearing affected by electricity, in the manner deſcribed above, but it is even ſenſible to the ſmell and the taſte. If a pointed braſs rod be electrified, either by being faſtened to the prime conductor, or held in the hand of a perſon electrified, and another perſon ſtanding upon the floor preſent his noſtrils within an inch or two of the point, he will feel a ſtrong and diſagreeable ſmell, like that of burning ſulphur; and if he receive the electric effluvia iſſuing from the point upon his tongue, he will perceive a taſte which is manifeſtly acid.

The machine, as repreſented Fig. 2, was ſuch as my ingenious friend the Rev. Mr. Timothy Prieſtley uſed, on account of its ſimple conſtruction, as not being liable to be out of order ſoon, having no wheel or ſtring either to make any noiſe or need alteration; it may be fixed firm on a table, and taken off in a moment; and the globe may be taken out with the greateſt eaſe, in

order to be packed up. When the inſide of the globe is lined with his compoſition, hereafter mentioned, it will produce more fire than with any other compoſition which I know of.

The ſpring S that is repreſented in the plate, is for thoſe that care not for having the rubber inſulated; but thoſe that are more curious may have them made with the rubber well inſulated by a glaſs pillar, that will hold the rubber to the back part of the globe, as repreſented Plate IV. Fig. 1.

The conſtruction of the electrical machine.

Fig. 2. A is a piece of mahogany, 9 inches ſquare, and 1 inch 1 quarter thick, in which a pedeſtal B is fixed; C is an iron axle, to which is fixed a braſs cap, and to which the globe G is firmly cemented, and runs in a braſs ſocket E, through the middle of the pedeſtal B, and turned by the handle H.

R is the rubber, which is made of a piece of wood cut to the curve of the globe, to which is fixed a leather covering, which being at a little diſtance from the wood in the middle, it will yield to the preſſure of the globe the better.

On this leather is another leather, which will take off by taking out a pin: on this the amalgam is rubbed, and being ſo eaſily taken off, is more readily brought into order than thoſe which have only one leather, and that fixed to the rubber. To this outermoſt leather is fixed a piece of black ſilk, which reaches half round the globe, and greatly increaſes the fire, ſo that it will give fire well, if the rubber ſcarce touch the

the globe. This machine will ſuit any kind of conductor; but I prefer paper globes covered with tin-foil, they being, in my opinion, the moſt compact, and retain the electrical effluvia better than any other ſhape.

Of the Influence of Points in Electricity.

THE more acutely pointed any bodies are, the more eaſily do they take or part with the electric matter. Thus, if a needle, or ſharp-pointed wire, be faſtened to the prime conductor, it will retain but a ſmall degree of electricity, and conſequently will give but a ſmall ſpark when the finger or a piece of metal is preſented to it. Alſo, if the needle, or ſharp pointed wire, be held in the hand of a perſon ſtanding upon the floor, and preſented to the conductor, it will likewiſe be found to retain but a ſmall degree of electricity. In the former of theſe caſes, while the needle was in contact with the prime conductor, the electric matter went off at the point, and was diſperſed in the air, or among the conducting particles, which are always floating in the common atmoſphere. In the latter caſe the needle being preſented towards the conductor, received the electric matter from it at a conſiderable diſtance.

If theſe experiments be made in the dark, a flame will be ſeen at the point of the needle or wire; but the appearance of the fire will not be the ſame in both caſes, but conſiderably different; ſo that it may always be perceived by the eye, whether, according to the common theory, the point be receiving or giving out the electric matter.

If the ſharp pointed wire be giving out the electric matter, the flame will be large; the parts of which it

conſiſts will be fewer; and if the point be not very acute, a kind of ſnapping noiſe will be heard as the electric matter is iſſuing out of it into the air; whereas, if the pointed wire be receiving the electric matter, the flame will be much ſmaller and more globular; the parts of which it conſiſts will be more in number, and the noiſe that is made will be a kind of hiſſing. The flame iſſuing from a body, on account of its oblong form, is called a pencil; and when the rays come to a point they project more equally from the centre, and it is then called a ſtar.

The reaſon why pointed bodies tranſmit the electric fluid with ſo much eaſe, has not yet been thoroughly explained; but the effects of it are exceedingly remarkable. The capital uſe that has been made of this obſervation, has been to draw the electric matter from the clouds, and thereby to prove that lightning and electricity are the ſame thing: for if a long rod or pole with a ſharp pointed wire at one end of it, be ſupported by electric ſubſtances, the point projecting towards the clouds will draw the electric matter from them, and become ſenſibly charged with electricity; juſt as it would have been from being connected with the prime conductor of an electrical machine. It will attract light bodies, ſparks of electric matter may be drawn from it, and it will exhibit every other appearance of common electricity; as, on the other hand, by common electricity, we can produce in miniature all the known effects of lightning.

Fig. 6. Several amuſing experiments depend on this property of pointed bodies, to tranſmit the electric fluid. If a plate of tin be cut into the form of a ſtar, and be ſupported

ported on its center D by a wire projecting from the prime conductor AB; as ſoon as the wheel of the machine is turned, and this apparatus electrified, a flame will appear at the extremity of every angle of the ſtar, which will be very beautiful; and if the ſtar be made to turn ſwiftly on its center, an entire circle of fire will be ſeen in the dark. This experiment will be very ſurprizing to perſons unacquainted with electricity, if the operator now an then privately touch the prime conductor, which may eaſily be managed, as it is performed in the dark; for by this means he may command the appearing or diſappearing of the ſtar, or circle of fire, at pleaſure.

If two ſharp pointed wires be bent, with the four ends at right angles, in the ſame plane, but pointing different ways, and be made to turn upon a center D; the moment it is electrified a flame will be ſeen at the points abcd; but what is moſt ſurprizing in the experiment is, that the wire will, at the ſame time, begin to turn round in the direction oppoſite to that to which the points are turned, as if ſome viſible power acted upon the points, and puſhed againſt them; and if the electrification be continued, the motion will preſently become very rapid.

Electrical horſe race.

If the figures of horſes, cut in paper, be faſtened upon theſe wires, and they be ſo contrived that the points ſhall be in their tails, the experiment will be very beautiful; the horſes will ſeem to purſue one another, though without a poſſibility of any of them overtaking the reſt; and this is called the electrical horſe race. It is poſſible to make ſeveral of theſe wires, each having a conſiderable number of points bent backwards, with horſes, &c. faſtened to each of them,

them, and turning one above another; and then ſome of them may be contrived to move faſter than the others. They may alſo be made to move different ways.

Promiſcuous Experiments.

THE reader in the courſe of this work muſt obſerve in ſeveral of the experiments already deſcribed, the remarkable property that points have, both of throwing off and receiving ſilently the electric fluid; but hereafter I ſhall deſcribe ſome more curious experiments of this kind, by which the influence of points, in reſpect of electricity, may be better underſtood, and which may in a more particular manner demonſtrate the utility of metallic conductors to houſes or piles of building, in order to preſerve them from the damage often occaſioned by a ſtroke of lightning; which is one of the greateſt beneſits that mankind has received from the ſcience of electricity.

The Dancing Balls.

Experiment I. FIX a pointed wire on the prime conductor, with the point outward; then take a glaſs tumbler, graſp it with your hands, and preſent its inſide ſurface to the point of the wire on the prime conductor while the machine is in motion; the glaſs in this manner will ſoon become charged; for its inſide ſurface acquires the electricity from the point, and its outſide loſes its natural quantity of electric fluid through the hands, which ſerves as a coating. This done, put a few pith balls on the table, and cover them with this charged glaſs tumbler. The balls will immediately begin to leap up along the ſides of the glaſs, as repreſented, and will continue their motion for a conſiderable time.

Fig. 9.

In this experiment the pith balls are attracted and repelled

pelled by the electric fluid ſuperinduced upon the inſide ſurface of the glaſs, which they gradually conduct to the table, or other conducting body upon which the glaſs is ſet; at the ſame time that the outward ſurface of the glaſs acquires the electric fluid from the contiguous air. This experiment may be made more diverting by having a glaſs cylinder three inches long, and the ſame in width, open at both ends, with a braſs plate fixed on its top; put any number of balls you pleaſe, and electrify the braſs cover, and the balls will dance with a very rapid motion, which will continue as long as the operator turns the machine.

To prove that Glaſs and other Electrics become Conductors, when they are made very hot.

IN order to aſcertain the conducting quality of hot reſinous ſubſtances, oils, &c. bend a glaſs tube in the form of an arch C E F D, and tie a ſilk ſtring C G D to it, which ſerves to hold it by, when it is to be ſet near the fire: fill the middle part of this tube with roſin, ſealing-wax, &c. then introduce two wires, A E, B F, through its ends, ſo that they may touch the roſin, or penetrate a little way in it. This done, let a perſon hold the tube over a clear fire, ſo as to melt the roſin within it; at the ſame time, by connecting one of the wires A or B with the outſide of a charged jar, and touching the other with the knob of the jar, endeavour to make the diſcharge through the roſin, and you will obſerve that, while the roſin is cold, no ſhocks can be tranſmitted through it; but it becomes a conductor, according as it melts; and when totally melted, then the ſhocks will paſs through it very freely. Experiment II. Fig. 10.

The

The Thunder-Houſe

Experiment III. Fig. 11. IS an inſtrument repreſenting the ſide of a houſe, either furniſhed with a metallic conductor, or not; by which both the bad effects of lightning ſtriking upon a houſe not properly ſecured, and the uſefulneſs of metallic conductors may be clearly repreſented. A is a board about three quarters of an inch thick, and ſhaped like the gable end of a houſe. This board is fixed perpendicularly upon the bottom board B, upon which the perpendicular glaſs pillar CD is alſo fixed in a hole about eight inches diſtant from the baſis of the board A. A ſmall hole ILMK about a quarter of an inch deep, and nearly one inch wide, is made in the board A, and is filled with a ſquare piece of wood, nearly of the ſame dimenſions. I mention nearly of the ſame dimenſions, becauſe it muſt go ſo eaſily into the hole, that it may drop off by the leaſt ſhaking of the inſtrument. A wire LK is faſtened diagonally to this ſquare piece of wood. Another wire III of the ſame thickneſs, having a braſs ball H ſcrewed on its pointed extremity; is faſtened on the board A; ſo alſo the wire MN, which is ſhaped in a ring at O. From the upper extremity of the glaſs pillar CD, a crooked wire proceeds, having a ſpring ſocket F, through which a double knobbed wire ſlips perpendicularly, the lower knob G of which falls juſt above the knob H. The glaſs pillar DC muſt not be made very faſt into the bottom board; but it muſt be fixed ſo as it may be pretty eaſily moved round its own axis, by which means the braſs ball G may be brought either nearer or farther from the ball H, without touching the part EFG. Now, when the ſquare piece of wood LMIK (which may repreſent the ſhutter of

of a window or the like) is fixed into the hole, ſo that the wire L K ſtands in the dotted repreſentation I M, then the metallic communication from H to O is complete, and the inſtrument repreſents a houſe furniſhed with a proper metallic conductor; but if the ſquare piece of wood L M I K is fixed ſo that the wire L K ſtands in the direction L K, as repreſented in the Figure, then the metallic conductor H O, from the top of the houſe to its bottom, is interrupted at I M; in which caſe the houſe is not properly ſecured.

Fix the piece of wood L M I K, ſo that its wire may be as repreſented in the Figure, in which caſe the metallic conductor H O is diſcontinued. Let the ball G be fixed at about half an inch perpendicular diſtance from the ball H, then, by turning the glaſs pillar D C, remove the former ball from the latter: by a wire or chain, connect the wire E F with the wire Q of the jar P, and let another wire or chain, faſtened to the hook O, touch the outſide coating of the jar. Connect the wire Q with the prime conductor, and charge the jar: then, by turning the glaſs pillar D C, let the ball G come gradually near the ball H, and when they are arrived ſufficiently near one another, you will obſerve that the jar explodes, and the piece of wood L M I K is puſhed out of the hole to a conſiderable diſtance from the thunder-houſe. Now the ball G in this experiment, repreſents an electrified cloud, which when it is arrived ſufficiently near the top of the houſe A, the electricity ſtrikes it; and as this houſe is not ſecured with a proper conductor, the exploſion breaks part of it, *i. e.* knocks off the piece of wood I M.

Repeat the experiment with only this variation, viz. that this piece of wood I M is ſituated ſo that the wire L K may ſtand in the ſituation I M, in which caſe the conductor H O is not diſcontinued; and you will obſerve, that the exploſion will have no effect upon the piece of wood L M, this remaining in the hole unmoved; which ſhews the uſefulneſs of the metallic conductor.

Further, unſcrew the braſs ball H from the wire HI, ſo that this may remain pointed, and with only this difference in the apparatus, repeat both the above experiments; and you will find the piece of wood I M is in neither caſe moved from its place, nor any exploſion will be heard.

Of the Electrical Battery.

Fig. 12. A number of coated jars connected together in ſuch manner that their whole force may be united, and act like one jar, conſtitutes what is called an electrical battery. This battery is the moſt formidable and entertaining part of an electrical apparatus; and by its uſe many wonderful effects are produced.

If a battery is required of no very great power, as containing about eight or nine ſquare feet of coated glaſs, I ſhould recommend to make uſe of common pint or half pint phials, ſuch as apothecaries uſe. They may be eaſily coated with tin-foil on the outſide, and braſs filings on the inſide; they occupy a ſmall ſpace, and on account of their thinneſs hold a very good charge. But when a large battery is required, then theſe phials cannot

cannot be uſed, for they break very eaſily; and for that purpoſe cylindrical glaſs jars of about fifteen inches high and four or five inches in diameter, are the moſt convenient.

When glaſs plates or jars, having a ſufficiently large opening, are to be coated, the beſt method is to coat them with tin-foil on both ſides, which may be fixed upon the glaſs with paſte made of wheat-flour; but in caſe the jars have not an aperture large enough to admit the tin-foil, and an inſtrument to adapt it to the ſurface of the glaſs, then braſs-filings, ſuch as are ſold by the pin-makers, may be advantageouſly uſed; and they may be ſtuck with gum-water, bees wax, &c. Care muſt be taken that the coatings do not come very near the mouth of the jar, for that will cauſe the jar to diſcharge itſelf. If the coating is about two inches below the top, it will in general do very well; but there are ſome kinds of glaſs eſpecially tinged glaſs, that when coated and charged, have the property of diſcharging themſelves more eaſily than others, even when the coating is five or ſix inches below the edge. There is another ſort of glaſs like that of which Florence flaſks are made, which, on account of ſome unvitrified particles in its ſubſtance, is not capable of holding the leaſt charge; on theſe accounts therefore, whenever a great number of jars are to be choſen for a large battery, it is adviſeable to try ſome of them firſt, ſo that their quality and power may be aſcertained.

A battery compoſed of twelve jars coated in the inſide and outſide with tin-foil, which altogether contain about twelve feet of coated glaſs. About the middle of each of theſe jars is a cork that ſuſtains a wire, which at the top

is faſtened round, or ſoldered to the wire E, knobbed at each end; which connects the inſide coatings of three jars; and by four wires, ſuch as F F, the inſide coatings of all the twelve jars may be connected together. Each of the wires F, has a ring at one end, through which one of the wires E paſſes, and the other end has a braſs knob. If the whole force of the battery is not required, one, two, or three rows of jars may be uſed at pleaſure; for as each of the wires FF is moveable round the wire E, which paſſes through its ring, and reſts upon the next wire E, it may be eaſily removed from that, and turned upon the contrary wire E; and thus the communication between one row of jars and another may be diſcontinued at pleaſure. *See the Figure.*

The ſquare box that contains theſe jars is of wood, lined at the bottom with tin-foil, and has two handles on two oppoſite ſides, by which it may be eaſily removed. In one ſide of the box is a hole through which an iron hook paſſes, which communicates with the metallic lining of the box, and conſequently with the outſide coating of all the jars. To this hook is faſtened a wire, the other end of which is connected with the diſcharging rod.

Fig. 4. The diſcharging rod conſiſts of a glaſs handle A, and two curved wires B B, which move by a joint C, fixed to the braſs cap of the glaſs handle A. The wires BB are pointed, and the points enter the knobs D D, to which they are ſcrewed, and may be unſcrewed from them at pleaſure. By this conſtruction we have the opportunity of uſing the balls or the points as occaſion requires; and as the wires are moveable by the joint C, they may be adapted to ſmaller or larger at pleaſure.

The

The battery repreſented in the plate, is a ſmall one in compariſon to thoſe now frequently uſed, and much too weak for the purpoſe of ſome experiments. But I thought it ſufficient to give an idea of its conſtruction; and when a large battery is to be conſtructed, I would recommend rather to make two, three, or more ſmall ones as repreſented in the plate, than a ſingle large battery, which is heavy, and, on ſeveral accounts, inconvenient. The force of ſeveral ſmall batteries may be eaſily united by a wire or chain; and thus they may be made to act in every reſpect like a large one. The beſt conſtruction of a battery is to have a wire from every jar, connected with a ball at the top, in form of a wire-cage.

The force of accumulated electricity, great as it appears by the experiments performed with a ſingle coated jar, is very ſmall when compared with that which is produced by a number of jars connected together; and if the effects of a ſingle jar are ſurpriſing, the prodigious force of a large battery is certainly aſtoniſhing. To obſerve that the metals, even the moſt putrified platina, which reſiſt the greateſt efforts of chemic fire, are actually, and almoſt inſtantaneouſly rendered red hot, and fuſed; to ſee animals deſtroyed, and to hear the loud report of a large electric battery, are things that always produce a kind of terror in the mind of an attentive obſerver. Experiments of this kind ſhould be conducted with great caution; and the operator ought to be attentive not only to the buſineſs in hand, but alſo to the perſons who may happen to be near him, prohibiting their touching, or even coming too near any part of the apparatus: for if a miſtake in performing other experiments may be diſagreeable, thoſe in the diſcharge of a large battery may be attended with worſe conſequences.

When

When a battery is to be charged, inſtead of a large prime conductor, a ſmall one is much more convenient: for in this caſe, the diſſipation of the electricity is not ſo conſiderable. The quadrant electrometer, which ſhews the height of the charge in the battery, may be fixed either upon the prime conductor, or upon the battery; in which caſe, it ſhould be fixed upon a rod proceeding from the wires of the jars; and if the battery be very large, it ſhould be elevated two or three feet above them.

The index of the electrometer in charging a large battery will ſeldom riſe ſo high as 90°, becauſe the machine cannot charge a battery ſo high in proportion as a ſingle jar. Its limit is often about 60° or 70°, more or leſs, in proportion to the ſize of the battery and the force of the machine.

The Spider ſeemingly animated by Electricity.

Experiment IV. Fig. 14. AN electric jar, having a wire CDE, faſtened on its outſide, which is bended ſo as to have its knob E as high as the knob A. B is a ſpider made of cork with a few ſhort threads run through it to repreſent its legs. This ſpider is faſtened at the end of a ſilk thread, proceeding from the ceiling of the room, or from any other ſupport, ſo that the ſpider may hang mid-way between the two knobs AE, when the jar is not charged. Let the place of the jar upon the table be marked; then charge the jar by bringing its knob A, in contact with the prime conductor, and replace it in its marked place. The ſpider will now begin to move from knob to knob, and continue this motion for a conſiderable time, ſometimes for ſeveral hours.

The

The inſide of the jar being charged poſitively, the ſpider is attracted by the knob A, which communicates to it a ſmall quantity of electricity: the ſpider then becoming poſſeſſed of the ſame electricity with the knob A, is repelled by it, and runs to the knob E, where it diſcharges its electricity, and is then again attracted by the knob A, and ſo on. In this manner the jar is gradually diſcharged; and when the diſcharge is nearly completed, the ſpider finiſhes its motion.

The Spiral Tube.

An inſtrument compoſed of two glaſs tubes CD, one within another, and cloſed with two knobbed braſs caps A and B. The innermoſt of theſe tubes has a ſpiral row of ſmall round pieces of tin-foil, ſtuck upon its outſide ſurface, and lying at about one-thirteenth of an inch from each other. If this inſtrument be held by one of its extremities, and its other extremity be preſented to the prime conductor, every ſpark that it receives from the prime conductor, will cauſe ſmall ſparks to appear between all the round pieces of tin-foil ſtuck upon the innermoſt tube, which in the dark affords a pleaſing ſpectacle, the inſtrument appearing encompaſſed by a ſpiral line of fire. Experiment V. Fig. 18.

The ſmall round pieces of tin-foil are ſometimes ſtuck upon a flat piece of glaſs A B C D, ſo as to repreſent curve lines, flowers, letters, &c. and they are illuminated after the ſame manner as the ſpiral tube; *i. e.* by holding the extremity C or B in the hand, and preſenting the other extremity to the prime conductor when the machine is in motion. They may alſo be fixed in any other poſition by having connecting wires. Fig. 19.

To

To ſhew that the Electric Fluid prefers a ſhort Paſſage through the Air to a long one through good Conductors.

Experiment VI. Fig. 16.

BEND a wire about ten feet long, at the ends of which fix a piece of glaſs G, to keep the parts A B at a proper diſtance, ſo that they may ſlide within half an inch of one another if required; then connect the chains belonging to the ſliding wires with the hook of the battery and the diſcharging rod, and ſend the charge of a battery through it. On making the exploſion, a ſpark will be ſeen between A and B, which ſhews that the electric fluid chuſes rather a ſhort paſſage through the air than a long one through the wire. The charge, however, does not paſs entirely through A and B, but part of it alſo goes through the wire, which may be proved by putting a ſlender wire between A and B; for on making the diſcharge, with only this addition in the apparatus, the ſmall wire will hardly be made red-hot, whereas if the large wire ADB be cut in D, ſo as to diſcontinue the circuit ADB, the ſmall wire will be melted, and even exploded by the ſame ſhock that before made it ſcarcely red-hot. In this manner the conducting power of different metals may be tried, uſing metallic circuits of the ſame length and thickneſs, and obſerving the difference of the paſſage through the air in each.

To ſwell Clay, and break ſmall Tubes with Electric Exploſion.

Experiment VII. Fig. 22.

ROLL up a piece of ſoft tobacco-pipe clay in a ſmall cylinder CD, and inſert in it two wires AB, ſo that their ends within the clay may be about a fifth part of an inch from

from one another. If a ſhock be ſent through this clay, by connecting one of the wires A or B with the outſide of a charged jar, and the other with the inſide, it will be inflated by the ſhock; *i. e.* by the ſpark that paſſes between the two wires, and after the exploſion, will appear as repreſented, Fig. 23. If the ſhock ſent thro' it is too ſtrong, and the clay not very moiſt, it will be broken by the exploſion, and its fragment ſcattered in every direction Fig. 23.

To make this experiment with a little variation, take a piece of the tube of a tobacco-pipe, about one inch long, and fill its bore with moiſt clay, then inſert in it two wires, as in the above rolled clay, and ſend a ſhock through it. This tube will not fail to burſt by the force of the exploſion, and its fragments willbe ſcattered about to a great diſtance.

If, inſtead of clay, the above-mentioned tube of the tobacco-pipe, or a glaſs tube (which will anſwer as well) be filled with any other ſubſtance, either electric or non-electric, inferior to metal, on making the diſcharge, it will be broken in pieces with nearly the ſame force.

An Electrometer:

WHICH conſiſts of a lined thread, having at each end a ſmall cork or pith-ball. This electrometer is ſuſpended by the middle of the thread on any conductor proper for the purpoſe, and ſerves to ſhew the kind and quantity of its electricity, by applying a ſtick of ſealing wax excited, or an excited ſmooth glaſs tube to the balls, which will recede or collapſe when the above wax or tube are applied alternately. By this means it will ſhew Fig. 13.

whether the conductor be charged poſitively or negatively; for if it be charged poſitively by applying the excited glaſs, the balls will recede ſtill further aſunder, and on applying the excited wax, they collapſe together.

The Univerſal Diſcharger:

Fig. 8. WHICH is of extenſive uſe, and is compoſed of the following parts: A is a flat board fifteen inches long, four inches broad, and one thick, or thereabouts, which forms the baſis of the inſtrument. B B are two glaſs pillars cemented in two holes upon the board A, and furniſhed at the top with braſs caps, each of which has a turning joint, and ſupports a ſpring tube, through which the wire D C ſlides. Each of theſe caps is compoſed of three pieces of braſs, connected ſo, that the wire D C, beſides its ſliding through the ſocket, has two other motions, viz. an horizontal and vertical one. Each of the wires D C, D C, is furniſhed with an open ring at one end, and at the other end has a braſs ball, D, which, by a ſhort ſpring ſocket, is ſlipt upon its pointed extremity, and it may be removed from it at pleaſure. E is a ſtrong circular piece of wood five inches in diameter, having, on its ſurface, a ſlip of ivory inlaid, and furniſhed with a ſtrong cylindrical foot, which fits the cavity of the ſocket F, which is faſtened in the middle of the bottom board, and has a ſcrew G, which ſerves to faſten the foot of the circular board E at any required height.

To prove that the Electric Spark diſplaces and rareſies the Air.

Experiment VIII. Fig. 24. THE electrical thermometer being very uſeful to obſerve the effects of the electric exploſion upon air, the

the body of this thermometer conſiſts of a glaſs tube, A B, about ten inches long, and nearly two inches diameter; and cloſed air-tight at both ends by two braſs caps. Through a hole in the upper cap, a ſmall tube, H A, opens at both ends, is introduced in ſome water, at the bottom B of the large tube. Thro' the middle of each of the braſs caps, a wire FGEI is introduced, having a braſs knob within the glaſs tube, and by ſliding through the caps, they may be ſet any diſtance from each other. This inſtrument is, by a braſs ring C, faſtened to the pillar of the wooden ſtand C D, that ſupports it. When the air within the tube A B is rarefied, it will preſs upon the water at the bottom of the tube, which will conſequently riſe in the cavity of the ſmall tube; and as this water riſes higher or lower, ſo it ſhews the greater or leſs rarefaction of the air within the tube A B, which has no communication with the external air.

If the water when this inſtrument is to be uſed, is all at the bottom of the large tube, *i. e.* none of it is in the cavity of the ſmall tube; it will be proper to blow with the mouth into the ſmall tube, and thus cauſe the water to riſe a little in it; where, for better regulation, a mark may be fixed.

Bring the knobs G I of the wires I E, F G, into contact with one another, then connect the ring E or F with one ſide of the charged jar, and the other ring with the other ſide, by which operation a ſhock will be made to paſs through the wires I G, I E, *i. e.* between the knobs G I. In this caſe you will obſerve that the water in the ſmall tube is not at all moved from the mark; which ſhows that the paſſage of the electric fluid, through conductors ſufficiently large, occaſions no rarefaction, nor diſplaces the air about them.

Put the knobs G I a little diſtant from one another, and ſend a ſhock through them as before, and you will ſee that the ſpark between the two knobs not only diſplaces, but rarefies conſiderably the air; for the water will be ſuddenly puſhed almoſt at the top of the ſmall tube, and immediately it will ſubſide a little; as for inſtance, as far as H; which is occaſioned by the ſudden diſplacing and replacing of the air about the place where the ſpark appeared within the tube A B. After that the water has ſubſided ſuddenly from the firſt riſing, it will then gradually and ſlowly come down to the mark at which it ſtood before the exploſion; which is the effect of the air that was rarefied, and which gradually returns to its former temperature.

If this experiment be made in a room where the degree of heat is variable, then proper allowance muſt be made for this circumſtance, in eſtimating the event of the experiment; for the electrical air-thermometer is affected by heat or cold in general, as well as by that cauſed by an electric ſpark.

The Courſe of the Electric Fluid in the Diſcharge, rendered viſible by the Star and Pencil.

Fig. 15. WHEN a jar is charged, take a diſcharging rod having its ends pointed; *i. e.* the diſcharging rod repreſented in Fig. 4, without its knobs, and keep it as repreſented Fig. 15; *i. e.* in ſuch a ſituation, that one of its points C may be at about one inch diſtance from the knob A, and the other point B, at an equal diſtance from the outſide coating of the jar: by theſe means the jar will be diſcharged ſilently; and if its inſide be electrified poſitively, you will ſee that the point of the diſcharging rod

is

is illuminated with a ſtar, and the point B with a pencil; becauſe, in this caſe, the electric fluid, going from the inſide to the outſide of the jar, enters the point C, and iſſues from the point B. But if the jar is electrified negatively on the inſide, and conſequently poſitive on the outſide, then the pencil of rays will appear upon the point C, and the ſtar upon the point B: for in this caſe the electric fluid paſſes from the outſide to the inſide of the jar. This experiment, as well as any other in which the electric light is to be obſerved, requires to be made in the dark.

The Leyden Vacuum.

A SMALL phial coated on the outſide about three inches up the ſide with tin-foil; at the top of the neck of this phial a braſs cap is cemented, having a hole with a valve; and from the cap a wire proceeds a few inches within the phial, terminating in a blunt point. When this phial is exhauſted of air, a braſs ball is ſcrewed upon the braſs cap, which is cemented into its neck, ſo as to defend the valve, and prevent any air from getting into the exhauſted glaſs. The inſide of this phial requires no coating, becauſe, as the electric fluid pervades vacuum, it can paſs freely from the wire to the ſurface of the exhauſted glaſs, without the help of a non-electric coating. This phial exhibits clearly the direction of the electric fluid both in charging and diſcharging; for if it be held by its bottom, and its braſs knob be preſented to the prime conductor poſitively electrified, you will ſee that the electric fluid cauſeth the pencil of rays to proceed from the wire within the phial, as repreſented Fig. 21, and if it is diſcharged, a ſtar will appear in the place of

Fig. 20.

Experiment IX.

Fig. 21.

Plate IV

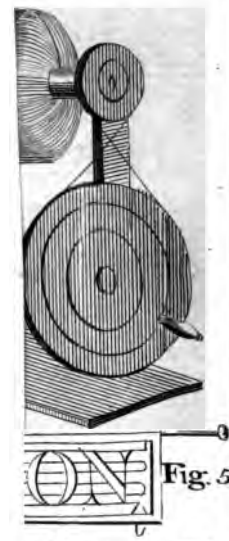
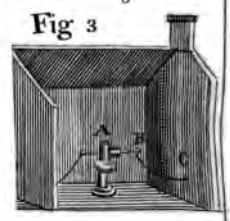


Fig. 5

Fig 3



Experiment X

Fig. 17.

other wire be touched with the knob of it, the explosion which must pass through the water from the knob of one of the wires to that of the other, will disperse the water, and break the glass with a surprising violence. This experiment is very dangerous, if not conducted with great caution.

The Powder-House

IS an ingenious contrivance, and well adapted to the purpose: the front is fitted up like the thunder-house; it is generally made 7 or 8 inches long, and nearly the same height to the top of the roof; the side and that half of the roof next the eye, is omitted in the figure, that the inside may be more conveniently seen. The sides, back, and front of the house are joined to the bottom by hinges; the roof is divided into two parts, which are also fastened by hinges to the sides; the building is kept together by a ridge fixed half-way on one side of the roof, so that when the building is put together, the other half of the ridge laps over the other half of the roof, and holds it together. Within the house there is a brass tube 1½ inch long, and 5-8ths of an inch in diameter screwed on a pedestal of wood; into the side of this brass tube is screwed a wire, which goes thro' 1-8th of an inch or better; the other end, by means of a chain, has a communication to the hook D; at the other side of the tube a piece of ivory, one inch long, is screwed, with a small hole for the wire to slide into. Plate IV. Fig. 3.

To use this apparatus, fill the glass tube A with gunpowder, and ram the wire B a small way into the ivory tube; then connect the hook C with the bottom of a large jar or battery; and when the jar, &c. is charged, form

form a communication from the book D to the top of the jar, &c. the diſcharge will then take place, and the exploſion of the gun-powder will throw aſunder the roof; and the ſides, the fore-front, and back-front will then fall down.

The Pyramid,

Fig. 4. As repreſented, Fig. 4, is deſigned to ſhew the ſame experiments as the thunder-houſe, and is uſed in the ſame manner. When the piece A is thrown out by the diſcharge, the upper part of the pyramid falls down; it is uſually made to repreſent a ſtone ſteeple, and is compoſed of ſeveral pieces; by which means, when the diſcharge is made, there appears greater devaſtation.

The Luminous Word.

Fig. 5. This experiment is exactly on the ſame principle as Fig. 18 and 19, Plate III. and the word is formed by the ſmall ſeparations made in the tin-foil; if they were cut a little round at every diviſion, the ſpark by that means would appear more vivid as it paſſed along the windings.

It may be obſerved in making theſe experiments, that the longer any word is, and the oftener the tin-foil is cut, the more powerful the machine muſt be, in order to convey the ſpark from one end to the other; becauſe every time the paſſage is interrupted by cutting, the ſpace is increaſed; and in long conveyances the ſpace will amount to more than the machine will be able to overcome.

There-

Therefore the ſhorter the illuminations are, the more pleaſing they will appear.

To ſhew how a Jar charges and diſcharges.

Coat a jar, as repreſented Fig. 6, by paſting ſmall pieces of tin-foil, at a little diſtance from each other, round its exterior ſurface. As this jar is charging, ſmall ſparks will paſs from one piece of tin-foil to another, in a variety of directions; the ſeparation of the tin-foil is the means of making the paſſage of the fluid, from the outſide of the jar to the table, viſible. Diſcharge this jar, by bringing a pointed wire gradually near the braſs ball, and the uncoated part of the glaſs, between the pieces of tin-foil, will be pleaſantly illuminated, and make a crackling noiſe; but if the jar is diſcharged ſuddenly, the whole outſide ſurface will appear illuminated. The glaſs muſt be very dry to produce theſe appearances to the greateſt advantage. Fig. 6.

How to make Inflammable Air that will take Fire by the Electric Spark.

Procure two bottles, as repreſented A D, Fig. 8; in the bottle D put about 2 or 3 ounces of iron filings, to which put ſome oil of vitriol, mixed with four times its quantity of water, fill the bottle A with water, and fix the bended glaſs-pipe C air-tight into the bottle D, and the other end a little way up the neck of the bottle A, and in a ſhort time the mixture will boil, and emit a fluid, which will paſs through the bended tube C into

the bottle A, and will at laſt fill it; expelling the water into the baſon B. The bottle A is then expeditiouſly corked up for uſe.

The Electrical Piſtol

Fig. 9. Is repreſented by a, b, c, d, e, Fig. 9; c, a, is made of thin braſs; to the mouth a, b, a cork is fitted; and a perforated piece of braſs e, ſcrews on the bottom of the piſtol at c, having a glaſs tube with a wire cemented into it, bended over the glaſs tube, ſo as to reach within one-eighth of an inch of the braſs; when the piſtol is to be charged uncork the inflammable air-bottle, likewiſe the piſtol, and place the mouth of the piſtol upon the top of the bottle, and the common air which is within the piſtol will deſcend while the other aſcends; keep the piſtol in this ſituation a few ſeconds, according to the ſtrength of the inflammable air, then expeditiouſly cork both the bottle and piſtol, and it is charged. To diſcharge it fill a ſmall jar or a hollow handle, and apply it to the little knob of the wire e, it will then explode, and drive out the cork to a conſiderable diſtance, making a report as loud as a piſtol filled with gunpowder.

The Conſtruction of a ſimple Orrery put into Motion by Electricity.

Fig. 1, Plate V. THIS orrery is for ſhewing the earth's motion round its axis in twenty-four hours, the age of the moon from change to change, and all her various phaſes during that time. A is the horizontal board or ſtand of this machine, and B is the great wheel, with eighteen floats or wings for the electric ſtream to act upon, and turn the

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XL

Fig. 9.

Fig. 1.
Plate V

the wheel according to the order of the letters a b c d. On the axis of this wheel is a trundle C, of eight ſtaves, for turning the wheel F, of thirty-two teeth, on whoſe axis is a trundle G, of eight ſtaves, for turning the wheel H, of fifty-nine teeth, which will go once round in the time the great wheel A goes twenty-nine and a half. A little hollow globe D, repreſenting the earth, with its meridians, equator, tropics, polar circles, and poles, is put upon the top of the axis of the great wheel A, and on the ſame axis is an index E, which goes round a ſmall dial-plate e of twenty-four hours, in the time that the earth D turns round. And an ivory ball I is placed on the top of the axis of the wheel H, half black, half white, to repreſent the moon; below which, on the ſame axis, is an index K, which goes round a ſmall plate k divided into twenty-nine and a half equal parts, for the days of the moon's age from change to change. So that, in the time the great wheel A, the earth D, and hour-index E, make twenty-nine and a half revolutions, the moon I and her index K make only one; and in that time, by ſhewing herſelf all round to the obſervers, they ſee all her different phaſes or appearances, like thoſe of the real moon in the heavens.

Having ſet the orrery near the prime conductor, place a crooked wire from the conductor, ſo as its point may be even with the great wheel B, and tend to turn it in the direction a b c d; turn the glaſs globe of the electrical machine by the winch, and a ſtream of fire will iſſue from the wire to the wheel, and turn the whole of the moveable work; by which means, the earth D will be turned round its axis, from weſt-by-ſouth to eaſt: and, in ſuch turn of the earth, the index E will go round Experiment XI.

all the twenty-four hours on the dial plate e. In the time the earth and index turn 29½ times round, the moon I, will turn once round her axis, ſhewing all her various phaſes; and the index K will go over all the 29½ days of the moon's age on the plate K.

A Model of a Water-Mill turned by a Stream of Electric Fire.

Fig. 4. A MODEL of a common mill for grinding corn. A is a water-wheel, B the cog-wheel on its axis, C the trundle turned by that wheel, and D the running mill-ſtone on the top of the axis of the trundle. It may eaſily be contrived and turned alſo by electricity, if inſtead of the round plate D for the mill-ſtone, there be a horizontal wheel on the axis of the trundle C with ſpur-cogs, which will turn two trundles placed on its oppoſite ſides; and on the top of each of theſe trundles axis, may be a round plate repreſenting a mill-ſtone; ſo that this model has all the working parts of a double water-mill, turning two mill-ſtones.

Experiment XII. Set the mill near the prime conductor, and place the crooked wire ſo as its point may be directed toward the uppermoſt ſide of the great wheel A. Then turn the glaſs globe by the winch, and the ſtream of fire that iſſues from the point of the wire will turn the wheel; and conſequently all the other working parts of the mill.

Another Electrical Orrery, ſhewing the Motion of the Sun, Earth, and Moon.

Fig. 3. THE ſun and earth go round the common center of gravity between them in a ſolar year; and the earth and moon go round the common center of gravity between them

them in a lunar month. Theſe motions are repreſented by an electrical experiment as follows:

The ball S repreſents the ſun, E the earth, and M the moon, connected by wires a c and b d: a is the center of gravity between the ſun and earth, and b is the center of gravity between the earth and moon. Theſe three balls and their connecting wires, are hung and ſupported on the ſharp point of a wire A, which is ſtuck upright in the prime conductor B of the electrical machine; the earth and moon hanging upon the ſharp point of the wire c a e, in which wire is a pointed ſhort pin, ſticking out horizontally at c; and there is juſt ſuch another pin at d, ſticking out in the ſame manner, in the wire that connects the earth and the moon.

Experiment XIII.

When the globe of the electrical machine is turned, the above-mentioned balls and wires are electrified: and the electrical fire, flying off horizontally from the point c and d, cauſe S and E to move round their common center of gravity a; and A and M to move round their common center of gravity b. And as E and M are light when compared with S and E, there is much leſs friction on the point b than upon the point a; ſo that E and M will make many more revolutions about the point b, than S and E make about the point a. The weights of the balls may be adjuſted ſo, that E and M may go twelve times round b in the time that S and E go once round a. It makes a good amuſing experiment in electricity; but it is ſo far from proving that the motions of the planets in the heavens are owing to a like cauſe, that it plainly proves they are not:—for the real ſun and planets are not connected by wires or bars of metal; and conſequently there can be no ſuch metallic points as c and d between

between them. And without ſuch points, the electric fluid would never cauſe them to move: for, take away theſe points in the above mentioned experiment, and the balls will continue at reſt, let them be ever ſo ſtrongly electrified.

The Electrified Capillary Syphon.

Fig. 6. LET a ſmall bucket of metal, full of water, be ſuſpended from the prime conductor, and put in it a glaſs ſyphon, of ſo narrow extremity as the water will juſt drop from it. If in this diſpoſition of the apparatus the winch of the machine be turned, the water which, when not electrified, only dropt from the extremity of the ſyphon, will now run in a full ſtream, which will even be ſubdivided into other ſmaller ſtreams; and if the experiment be made in the dark, it will be beautifully illuminated, and like a fountain with ſtreams of fire; which may be made to ſtop apparently by the word of command, by touching the prime conductor.

The Quadrant Electrometer.

Fig. 4. The only inſtrument that can with propriety be called an electrometer; that is, ſuch as meaſures the preciſe degree to which any body is electrified, is as follows: A is a very light rod, that turns on the center of a ſemicircle B, ſo as always to keep pretty near its graduated limb: at the extremity of the rod is a cork ball C. D is the pillar that ſupports the rod, and may be either fixed to the prime conductor, or let into the braſs knob of a

jar

jar or battery, or be ſet on a ſtand to ſupport itſelf. The whole inſtrument may be made of wood or ivory; but is found moſt perfect when the pillar and rod, or index, are of box, made very ſmooth with emery paper: the ball of cork, and the ſemicircle ivory, as the diviſions on that are more legible than on wood.

The moment this inſtrument begins to be electrified, the rod is repelled by the pillar, and conſequently begins to move over the edge of the ſemicircle, and ſhews, to the greateſt preciſion, the degree to which the prime conductor is electrified; or how high any jar or battery is charged. As the materials of which this inſtrument is made are very imperfect conductors, it will very rarely diſſipate any of the electricity of the prime conductor, &c. with which it is connected: but if it be found, by a trial in the dark, that any part of it collects the electric matter, it muſt be placed before the fire to dry off the damp, particularly from the index; it ſhould not however be much heated, for then it will not receive the electricity ready enough, and the motion of the index will not anſwer with ſufficient accuracy to the degree of electricity in the body with which it is in contact: but this inconvenience may be eaſily remedied by moiſtening the pillar and the index; for the ſemicircle can never be too dry.

It is evident, from the conſtruction of this inſtrument, that the force of different exploſions may be aſcertained by it, before the diſcharge, with the greateſt accuracy. If a jar be charged with poſitive electricity, and you want to know the preciſe time, while you are attempting to charge it negatively, that it becomes diſcharged, watch the moment the index comes to the perpendicular ſtation, which may be obſerved without the leaſt danger of

of a miſtake, and you will then find there is not the leaſt ſpark left in the jar. If you continue the operation, the index will begin to advance again; and thereby ſhew the exact quantity of the oppoſite electricity the jar has acquired.

A very uſeful Inſtrument to cure the Tooth-Ach.

Fig. 5. THE inſtrument A is a flat ſquare piece of box-wood, about an inch broad, and a quarter of an inch thick: two longitudinal holes are made quite through it, near its oppoſite edges, through which the braſs wires a b c and d e f are put while they are ſtraight; then fixed with ſealing-wax, and bent as in the figure, ſo as to receive the tooth and gum between their points c and f, which muſt not be made too ſharp for fear of hurting the gum. When it is uſed, two chains g and h muſt be hooked to the other ends of the wires, and holding it on the gum, with the tooth between the ends of c and f of the wires a b c and d e f, hook the chains g and h on the other ends of theſe wires; put the other end of a chain g round the bottom of a jar, and cauſe an aſſiſtant to hold the chain h, hanging down from his hand; the chains not touching one another, and both of them clear of the table. Then having charged the jar, deſire the aſſiſtant to ſtrike the prime conductor with the looſe end of the chain h; this will diſcharge the jar, and give the perſon a ſhock, which will be felt only in the tooth and gum that is taken in between the wires at c and f.

Practical

Practical Rules concerning the Use of the Electrical Apparatus, and the performing of Experiments.

IT often happens that young electricians are at a loss to assign the reason why some experiments do not succeed with them, as described in the Treatises on Electricity. Sometimes they are in possession of very good instruments; but by reason of some circumstance or other, unattended to, they are quite useless in their hands. This indeed can be remedied by nothing but practice; and it is by long use that the electrician, as well as the practitioner in any art or science, becomes so good an operator, as to use his instruments to the best advantage. A few rules are however very necessary to guide him in his operations; and although these alone are insufficient to make a person a complete practical electrician, yet, when accompanied with the actual management of the apparatus, they facilitate the use of it, and render the performance of the experiments more accurate and expeditious.

The first thing that the young electrician should observe, is, the preservation and care of his instruments. The electrical machine, the coated jars, and in short, every part of the electrical apparatus, should be kept clean, and as free as possible from dust and moisture.

When the weather is clear, and the air dry, especially in clear and frosty weather, the electrical machine will always work well: But when the weather is very hot, the machine is not so powerful; nor in damp weather,

except it be brought into a warm room, and the cylinder, the ſtands, the jars, &c. be made thoroughly dry.

Before the machine is uſed, the cylinder ſhould be firſt wiped very clean with a ſoft linen cloth that is dry, clean, and warm; and afterwards with a clean hot flannel, or an old ſilk handkerchief; this done, apply a little amalgam, and turn the winch, and it will ſoon be perceived that the electric fluid will come like a wind from the cylinder to the knuckle; and, if the motion be a little continued, ſparks and crackling will ſoon follow. This indicates that the machine is in good order; and the electrician may proceed to perform his experiments. But if, when the winch is turned for ſome time, no wind is felt upon the knuckle, then the fault is, very likely, in the rubber; and to remedy that, uſe the following directions: By unſcrewing the ſcrews on the back of the rubber, remove it from its glaſs pillar, and keep it a little near the fire, ſo that its ſilk part may be dried: take now a piece of dry mutton ſuet, or a little tallow from the candle, and juſt paſs it over the leather of the rubber, and then the machine cannot fail but be fit for uſe.

Sometimes the machine will not work well, becauſe the rubber is not ſufficiently ſupplied with electric fluid; which happens when the table upon which the machine ſtands, and to which the chain of the rubber is connected, is very dry, and conſequently in a bad conducting ſtate. Even the floor and the walls of the room are, in very dry weather, bad conductors, and they cannot ſupply the rubber ſufficiently. In this caſe the beſt expedient is, to connect the chain of the rubber by means of a long wire, with ſome moiſt ground, or with the iron-work of a water-pump; by which means the rubber

ber will be ſupplied with as much electric fluid as is required.

When a ſufficient quantity of amalgam has been accumulated upon the leather of the rubber, and the machine does not work very well, then, inſtead of putting more amalgam, it will be ſufficient to take the rubber off, and to ſcrape a little off that which is already upon the leather.

It will be often obſerved, that the globe or cylinder, after being uſed ſome time, contracts ſome black ſpots, occaſioned by the amalgam, or ſome foulneſs of the rubber, which grow continually larger, and greatly obſtruct its electric power. Theſe ſpots muſt be carefully taken off, and the cylinder muſt be frequently wiped, in order to prevent its contracting them.

In charging electric jars in general, it muſt be obſerved, that every machine will not charge them equally high. That machine whoſe electric power is the ſtrongeſt, will always charge the jars higheſt. If the coated jars, before they are uſed, be made a little warm, they will receive, and hold the charge the better.

If ſeveral jars are connected together, among which there is one that is apt to diſcharge itſelf very ſoon, then the other jars will alſo be ſoon diſcharged with that; although they may be capable of holding a very great charge by themſelves. When electric jars are to be diſcharged, the electrician muſt be cautious leſt, by ſome circumſtance not adverted to, the ſhock ſhould paſs through any part of his body; for an unexpected ſhock, though not very ſtrong, may occaſion ſeveral diſagreeable accidents. In making the diſcharge, care

muſt be taken that the diſcharging rod be not placed on the thinneſt part of the glaſs; for that may cauſe the burſting of the jar.

When a large battery is diſcharged, jars will be often found broken in it, which burſt at the time of the diſcharge. To remedy this inconvenience take this method; which is, Never to diſcharge the battery through a good conductor, except the circuit be at leaſt five feet long. Mr. Nairne ſays, that ever ſince he made uſe of this precaution, he has diſcharged a very large battery near a hundred times, without ever breaking a ſingle jar; whereas before, he was continually breaking them. But here it muſt be conſidered, that the length of the circuit weakens the force of the ſhock proportionably; the higheſt degree of which is in many experiments required.

It is adviſeable when a jar, and eſpecially a battery, has been diſcharged, not to touch its wires with the hand before the diſcharging rod be applied to its ſides a ſecond, and even a third time; as there generally remains a reſiduum of the charge: this reſiduum is occaſioned by the electricity, that, when the jar is charging, ſpreads itſelf over the uncoated part of the glaſs near the coating, which will not be diſcharged at firſt, but gradually returns to the coating after the firſt diſcharge, which is ſometimes very conſiderable.

When any experiment is to be performed, which requires but a ſmall part of the apparatus, the remaining part of it ſhould be placed at a diſtance from the machine, the prime conductor, and even from the table, if that is not very large. Candles, particularly, ſhould be placed

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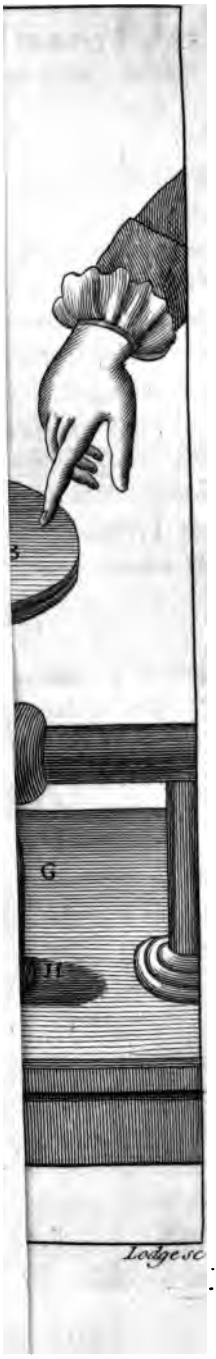
ig. 1.

PLATE VI



placed at a conſiderable diſtance from the prime conductor; for the effluvia of their flames carry off much of the electric fluid.

Laſtly, The young electrician ſhould be cautioned not to depend on firſt appearances in electricity. A new phenomenon may juſtly excite his curioſity: it is laudable to remark it, and to purſue the hint; but at the ſame time even the doubtful aſſertion of a new fact ſhould never be made, till after a number of ſimilar and concurring experiments. Electricity is a ſcience that often deceives the ſenſes; and the moſt experienced electrician frequently finds himſelf miſtaken in things, which perhaps he may have before conſidered as the moſt certain.

In many electrical experiments, it is very convenient to have a method of determining, whether a ſmall degree of electricity be poſitive or negative; and in uſing large batteries, it is a matter of conſequence to know how the charge advances, and of what ſtrength it is. Mr. Canton's balls are extremely uſeful for both theſe purpoſes. They are made of the pith of elder, turned perfectly globular, and ſuſpended from the conductor by fine threads. Plate VI. Fig. 1.

To underſtand the uſe of them, ſuppoſe a jar or battery ſtands upon the table, and I want to know whether the inſide be charged poſitively or negatively. In order to this, I preſent the balls, and they are immediately attracted by the wire, and diverge from one another. This is common to both electricities; and the greater the diſtance to which the balls ſeparate, and the farther they repel one another, the higher is the charge. To determine

mine of what kind it is, I rub a ſmall piece of glaſs (which I carry about me for the purpoſe) againſt my hand or coat, which I know will excite it poſitively, and then preſent it to the balls in their diverging ſtate. If it makes the balls converge, and conſequently avoid the glaſs, it ſhews that they are electrified poſitively, as well as the glaſs. On the contrary, if it increaſe their divergency, and attract them, it ſhews their electricity to be of a kind oppoſite to that of the glaſs; that is, negative. And it muſt be remembered, that the electricity of the balls (which do not touch, or receive any electricity from the wires of the jar or battery) is always contrary to that with which they are charged; for all bodies placed within the influence of electrified bodies, are affected with the contrary electricity.

In order to aſcertain the kind of an exceeding ſmall degree of electricity, it will be convenient to have a very light body; as a piece of downy feather hanging by a ſilken thread. This light body, when it is once electrified, either poſitively or negatively, will retain its virtue a long time, with very little loſs. If then any body (the electricity of which is unknown) be brought to it, the feather will be repelled by it, if it be of the ſame kind with its own, and attracted if it be the contrary to it. The ſilk, by which it is ſuſpended, ſhould be a ſingle thread, as it comes from the worm; or at leaſt a very few of thoſe threads; and the whole ſhould be as light as poſſible.

The Electrophorus.

IT conſiſts of two plates, A and B, made of a circular form, from ſix to eighteen inches diameter, or upwards. The upper plate is generally made of braſs; but a tin plate, with a wire turned in upon its edge, will anſwer exceeding

exceeding well. At the center of this plate there is a ſocket o, in which a glaſs handle I (nine or ten inches long) is fixed. A thin board, covered with tin-foil and ſuſpended by ſilken ſtrings, will anſwer well, when the electrophorus is wanted of a large diameter.

The under plate may be made of glaſs, ſealing-wax, or of the following compoſition, viz. Four parts roſin, three parts pitch, three parts ſhel-lac, two parts Venice-turpentine, melted together over a gentle fire. It may be poured and ſpread upon a thin linen cloth about one-fourth of an inch thick. The linen cloth muſt be ſtretched upon a hoop, and made as tight as poſſible. If the ſurface be a little rough, it will be no worſe.

The manner of uſing this machine is as follows: — Rub the coated ſide of the under plate A with new fine flannel, or a hare or cat's ſkin; and when it is excited as much as poſſible, ſet it on a table, and place the upper plate upon it, and put your finger on the upper plate: then take your finger off and take hold of the top of the glaſs handle I, and apply it to the knob of a coated jar. Repeat this operation for 30 or 40 times, and the jar will become charged.

Mr. Cavallo mentions one of the above kind which he made, with which he charged a coated phial ſeveral times (by once exciting) ſo ſtrong as to pierce a hole through a card at every diſcharge.

When a glaſs is coated with ſealing-wax, after it is excited and laid with the waxed ſide downward, and the glaſs uppermoſt, then on making the uſual experiment of putting the metal plate on it, and taking the ſpark, &c.

&c. it will be attended with contrary electricity to what it had before.

Medical Electricity.

BEFORE we conclude the ſubject, it will be neceſſary to give ſome rules, in order to explain a few practical experiments of applying medical electricity: and firſt, It ſhould be attentively obſerved, to apply the ſmalleſt force of electricity, which may be ſufficient to remove or alleviate any diſorder. The chief difficulty conſiſts in diſtinguiſhing the proper ſtrength of the electric power that is required for a given diſorder. The ſex and condition of the patient muſt be duly conſidered; and, in regard to this point, it is impoſſible to give any exact and invariable rules; the circumſtances being of ſuch a nature, and ſo various, that long experience, and a ſtrict attention to every particular phenomenon, are the only means by which proper inſtructions may be received. The ſureſt rule that can be given relating to this particular, is to begin with the moſt gentle treatment; at leaſt ſuch that, conſidering the conſtitution of the patient, may be thought rather weak than ſtrong. When this gentle treatment has been found ineffectual for a few days, which is denoted by the diſeaſe not abating, and the application of electricity not cauſing any material alteration, then the operator may gradually increaſe the force of electricity until he finds the proper degree of it.

In judging of caſes proper to be electrified, experience ſhews, that in general, all kinds of obſtructions, whether of motion, of circulation, or of ſecretion, are very often removed or alleviated by electricity. The ſame may alſo

alſo be ſaid of nervous diſorders; both which include a great variety of diſeaſes. The application of electricity has alſo been found very beneficial in diſeaſes of a long ſtanding. It has likewiſe been found a powerful remedy in muſcular contractions. But when any limb of the body is deprived of motion, it muſt be obſerved, that the deprivation of motion is not always originated by a contraction of the muſcles; but that it is often occaſioned by a relaxation: thus, for inſtance, If the hand is bent inwardly, and the patient has no power of ſtraightening it, the cauſe of it may be a weakneſs of the outward muſcles, as well as a contraction of the inward ones. In ſuch caſes it is often difficult, even for good anatomiſts to diſcover the real cauſe; but the ſureſt method is to electrify, not only thoſe muſcles which are ſuppoſed to be contracted, but alſo their antagoniſts; for to electrify a ſound muſcle is by no means hurtful.

Rheumatic diſorders, even of long ſtanding, are relieved, and generally quite cured, by only drawing the electric fluid with a point from the part, or by drawing ſparks from the conductor: the operation ſhould be continued for about four or five minutes, repeating it once or twice every day. When ſtrong ſhocks are adminiſtered, their greateſt number ſhould not exceed a dozen or fourteen, except when they are to be given to the whole body in different directions.

The inſtruments which, beſides the electrical machine and its prime conductor, are neceſſary for the adminiſtration of medical electricity, may be reduced to three, viz. an electric jar, with Mr. Lane's electrometer;

an inſulated chair, or an inſulated ſtool, upon which a common chair may be occaſionally ſet, and the directors.

Fig. 4. Repreſents the electric jar, with Mr. Lane's electrometer, and the manner in which the ſhocks are ſent thro' any part of the body. The ſurface of the jar, which is coated with tinfoil, ſhould be about four inches in diameter, and ſix inches high, which is equal to about ſeventy-three ſquare inches. The braſs wire, which paſſes thro' the covering of the jar, and touches the inſide coating, has a braſs ball F, to which the electrometer FDE is faſtened: and proceeding a little farther up, terminates in another braſs ball B, which ſhould be ſo high as to touch the prime conductor A, which is ſuppoſed to ſtand before the electrical machine. The electrometer conſiſts in a glaſs ſtick, F D, cemented to two braſs caps, F and D; from the latter of which a ſtrong perpendicular braſs wire proceeds, the extremity of which comes as high as the center of the ball B, and is furniſhed with an horizontal ſpring ſocket, through which the wire C E, having the braſs ball C at one end, and the open ring E at the other, may be ſlided backwards and forwards, ſo as to ſet the braſs ball C at any required diſtance from the ball B. This diſtance, at moſt, need not be greater than half an inch; hence the electrometer may be made very ſmall. Sometimes ſmall diviſions are marked upon the wire C E, which ſerve to ſet the balls B and C at a given diſtance from one another with more readineſs and preciſion. Now, ſuppoſe that the jar is ſet contiguous to the prime conductor; that is, with the ball B touching the conductor; that the ball C be ſet at 1-10th of an inch diſtant from the ball B; and that, by means of a chain, a conducting communication be formed from E to the outſide coating of the jar, by a chain

chain x. In this caſe, if the electrical machine be put in motion, the jar will be charged; and when the charge is ſo high as that the electric fluid accumulated within the jar can leap from the ball B to C, which we have ſuppoſed to be 1-10th of an inch aſunder, the diſcharge will happen, and a ſpark appear between the ſaid balls, and the ſhock paſſes through the chain x: for the part F D of the electrometer being of glaſs, generally covered with ſealing-wax, is impervious to electricity, conſequently the electric fluid has no other way through which it can paſs from the inſide to the outſide of the glaſs jar. When the ſhocks are to be given with this apparatus to any particular part of the body (for inſtance, to the arm) then, inſtead of the chain x, which muſt now be taken away, two ſlender and pliable wires, EL, IL, are to be faſtened, one to the open ring E of the electrometer, and to the braſs hook I of the ſtand H I, which communicates with the outſide coating of the jar. If the jar has not the ſtand H I, the extremity I of the wire I L may be ſimply reſted under, or may be tied round it. In ſhort, it muſt be put in contact with the outſide coating of the jar, in any convenient manner. The other extremities of the ſaid wires are faſtened each to the braſs wires L, and L of the directors K L, K L. Each of thoſe inſtruments, juſtly called directors, conſiſts of a knobbed braſs wire L, which by means of a braſs cap is cemented to the glaſs handle K. The operator, holding them by the extremity of the glaſs handle, brings their balls into contact with the extremities of that part of the body of the patient through which he deſires to ſend the ſhock. The management and convenience of this apparatus are eaſily comprehended by inſpecting the figure; for when the machine is in motion, and the apparatus, &c. is ſituated as in the figure,

the diſcharge of the jar muſt be evidently made through that part of the patient's arm which lies between the knobs of the directors; and the operator, whilſt an aſſiſtant keeps the machine in motion, has nothing more to do but to hold the knobs of the directors to the extremities of the arm, or to any other part of the body that is required to be thus electrified; always taking care that the two wires E L, I L, do not touch each other, becauſe in that caſe the ſhock will not paſs through that part of the body which is required to be electrified. Thus any number of ſhocks, preciſely of the ſame ſtrength, may be given, without altering any part of the apparatus, or having any farther trouble: and when the ſtrength of the ſhocks is required to be diminiſhed or increaſed, it is only neceſſary to diminiſh or augment the diſtance between the balls B C; which is done by ſlipping the wire C E forwards or backwards through the ſpring ſocket that holds it.

It is almoſt needleſs to mention, that when ſhocks are adminiſtered, it is immaterial whether the patient ſtands upon the ground, upon the inſulating ſtool, or in any other ſituation whatever. Neither is it always neceſſary to remove the clothes from the part that is to be electrified, in order to let the knobs of the directors touch the ſkin; for, except the coverings be too many and too thick, in which caſe part of them at leaſt ſhould be removed, the ſhocks will go through them very eaſily, eſpecially if the knobs of the directors be preſſed a little upon the part.

Of the Technical Terms uſed by Writers on the Subject of Electricity.

BATTERY, *electrical*, a number of jars combined together, ſo that they may be all charged and diſcharged at the ſame time. The form of one is exhibited, Fig. 12. Plate III.

Charging, throwing an additional quantity of electric matter upon one ſide of a plate of glaſs, or a jar, while the other ſide is exhauſted in the ſame proportion. All other electric ſubſtances are capable of being charged as well as glaſs.

Circuit, electric, thoſe conducting ſubſtances which are made uſe of to form a communication between the two coatings of a charged jar or battery, &c. and through which the electric matter muſt paſs, when the equilibrium between the two ſides is reſtored by the diſcharge.

Coatings, plates of metal, or other conducting ſubſtances, laid upon plates of glaſs, or other electrics, whereby the additional quantity of electric matter, called *the charge*, may be the more eaſily and uniformly conveyed to them, or diſcharged from them.

Conductor, prime, a piece of metal furniſhed with points, to receive electric matter from the globe, after it has been excited by friction. It muſt always be inſulated, or cut off from a communication with the earth by means of electric ſubſtances, ſuch as *glaſs*, *baked wood*, &c.

&c. Whenever *the conductor* is mentioned, the prime conductor muſt alſo be underſtood.

Conductors, or *conducting ſubſtances*, thoſe bodies thro' which the electric matter may be tranſmitted. They are alſo called non-electrics, becauſe no electric powers can be excited in them by friction.

Diſcharging, reſtoring the equilibrium of the electric fluid, after it has been diſturbed by charging. It is effected by forming a communication between the overloaded and the exhauſted ſide of a glaſs jar, battery, &c. by means of conducting ſubſtances, through which the overplus or charge may paſs from the one to the other. When the diſcharge is conſiderable, it is often called an *exploſion*.

Diſcharging rod, a braſs rod, with a knob at each end, very convenient either for taking ſparks from the prime conductor, or for diſcharging jars or batteries. It is ſometimes bent into a ſemicircular form, in order to bring one of the knobs to the outſide, and the other to the wire, communicating with the inſide of a charged jar, in order to diſcharge it, by receiving the exploſion on the knob.

Electric matter, that ſubtle fluid which is ſuppoſed to be the cauſe of all thoſe appearances which are termed electric. It is ſometimes called *electric fire*, and ſometimes *ether*.

Electrics, thoſe bodies in which electric powers of attraction, repulſion, &c. may be excited by friction. They are alſo called *non-conductors*, becauſe the electric matter cannot paſs through them.

Electrometers,

Electrometers, inſtruments to meaſure the degree of electrification; that is, the quantity of electric matter thrown upon any body, or the force of an electrical exploſion.

Excitation, the act of exciting or calling forth electric powers from electric ſubſtances, by means of friction, and other methods.

Inſulating, placing bodies where they are not in contact with any conducting ſubſtance; as by ſuſpending them in the air by ſilken ſtrings, putting them on glaſs ſtands, &c. ſo that the electricity they may be charged with cannot be conveyed to the earth.

Negative Electricity, a leſs quantity of the electric matter than is natural to any body.

Pencil, the appearance of electric light iſſuing from the point of a body electrified poſitively.

Poſitive Electricity, a quantity of electric matter thrown upon any body, above its natural ſhare.

Rubber, or cuſhion, a piece of leather, or any other ſubſtance againſt which the glaſs globe, or other electric body whirled in the machine, is rubbed, in order to excite them.

Shock, electric, the convulſion given to the animal muſcles by the paſſage of the electric matter through them, eſpecially in the diſcharging of a jar or battery.

Star,

Star, the appearance of electric light from the point of a body electrified negatively.

Wire of a phial, a jar, or battery, the wire or metal rod which goes into the phial, and which touches the inſide coating. This wire is therefore often put for the inſide coating.

Two Methods to make Amalgam.

FIRST, take ſpelter four ounces, and diſſolve it in an iron ladle over a fire; let it cool a little, but not ſo as to become quite ſtiff: add to it, while in that ſtate, ſix ounces of mercury, and ſtir them well up together; then turn it out of the ladle upon a ſmooth ſtone, and grind it with a mullet till it becomes like fine tough paſte; which put into a box, and it is ready for uſe. If it ſhould become too hard, grind it again with a little more mercury: the addition of a little tallow may be occaſionally added.

The Second Method.

TAKE of tin one pound; flour of ſulphur ſeven ounces; ſal ammoniac and purified quickſilver, of each half a pound.

Melt the tin by itſelf, add to it the quickſilver, and when the mixture is grown cold reduce it into powder: mix this with the ſulphur and ſal ammoniac, and ſublimate it in a matraſs: the moſaic gold will be found under the ſublimated matter, with ſome droſs at the bottom. This is thought as powerful an amalgam as the former.

A Com-

A Compoſition for lining the Inſide of Globes or Cylinders.

TAKE four parts of Venice turpentine, one part of roſin, and one of bees-wax, boil the whole over a gentle fire for two hours, and it is fit for uſe. When a globe or cylinder is to be lined, it muſt be put into an oven, with a ſufficient quantity of the compoſition, broken, and put in the inſide, and when it is melted it muſt be turned round every way, in order to ſpread it all over equally. This lining has been found to increaſe the electric power amazingly. Mr. Prieſtly uſed linſeed oil and roſin in the ſame manner as above directed, the proportion was equal parts of each, boiled very well together.

A Varniſh for all the Parts of the Machine which are inſulated.

TAKE ſpirits of wine, highly rectified, and in it diſſolve the beſt ſealing-wax to a tolerable ſtiff conſiſtence, with which varniſh over all your glaſs pillars, to keep off the moiſture they attract from damp air.

PNEUMATICS.

PNEUMATICS is that branch of natural philoſophy which treats of the nature, weight, preſſure, and elaſticity of air, and the effects ariſing therefrom.

Of the Properties of the Air.

THE air is that thin tranſparent fluid in which we live and breathe. It encompaſſes the whole earth to a conſiderable height; and, together with the clouds and vapours that float in it, it is called the *atmoſphere*. The air is juſtly reckoned among the number of fluids, becauſe it has all the properties by which a fluid is diſtinguiſhed; for, it yields to the leaſt force impreſſed, its parts are eaſily moved among one another, it preſſes according to its perpendicular height, and its preſſure is every way equal.

That the air is a fluid conſiſting of ſuch particles as have no coheſion betwixt them, but eaſily glide over one another and yield to the ſlighteſt impreſſion, appears from that eaſe and freedom with which animals breathe in

in it, and move through it without any difficulty or ſenſible reſiſtance.

But it differs from all other fluids, in the four following particulars: 1. It can be compreſſed into a much leſs ſpace then what it naturally poſſeſſeth. 2. It cannot be congealed or fixed, as other fluids may. 3. It is of a different denſity in every part upward from the earth's ſurface, decreaſing in its weight, bulk for bulk, the higher it riſes; and therefore muſt alſo decreaſe in denſity. 4. It is of an elaſtic or ſpringy nature, and the force of its ſpring is equal to its weight.

That air is a body, is evident from its excluding all other bodies out of the ſpace it poſſeſſes: for, if a glaſs jar be plunged with its mouth downward into a veſſel of water, there will but very little water get into the jar, becauſe the air, of which it is full, keeps the water out.

As air is a body, it muſt needs have gravity or weight; and that it is weighty, is demonſtrated by experiment. For, let the air be taken out of a veſſel by means of the air-pump, then having weighed the veſſel, let in the air again, and upon weighing it when refilled with air, it will be found conſiderably heavier. Thus a bottle that holds a wine quart, being emptied of air and weighed, is found to be about 16 grains lighter then when the air is let into it again; which ſhews that a quart of air weighs 16 grains. But a quart of water weighs 14621 grains: this divided by 16 quotes 914 in round numbers; which ſhews, that water is 914 times as heavy as air near the ſurface of the earth.

As the air riſes above the earth's ſurface, it grows rarer, and conſequently lighter, bulk for bulk; for ſince it is of an elaſtic nature, and its lowermoſt parts are preſſed with the weight of all that is above them, it is plain that the air muſt be more denſe or compact at the earth's ſurface than at any height above it; and gradually rarer the higher up. For the denſity of the air is always as the force that compreſſeth it: and therefore, the air toward the upper part of the atmoſphere being leſs preſſed than that which is near the earth, will expand itſelf, and thereby become thinner than at the earth's ſurface.

Dr. Cotes has demonſtrated, that if altitudes in the air be taken in arithmetical proportion, the rarity of the air will be in geometrical proportion. For inſtance,

At the Altitude of Miles above the ſurface of the earth, the air is	times thinner and lighter than at the earth's ſurface.
7	4
14	16
21	64
28	256
35	1024
42	4096
49	16384
56	65536
63	262144
70	1048576
77	4194304
84	16777216
91	67108864
98	268435456
105	1073741824
112	4294967296
119	17179869184
126	68719476736
133	274877906944
140	1099511627776

And

And hence it is eaſy to prove by calculation, that a cubic inch of ſuch air as we breathe would be ſo much rarefied at the altitude of 500 miles, that it would fill a ſphere equal in diameter to the orbit of Saturn.

The weight or preſſure of the air is exactly determined by the following experiment:

Take a glaſs tube about three feet long, and open at one end; fill it with quickſilver, and, putting your finger upon the open end, turn that end downward and immerſe it into a ſmall veſſel of quickſilver, without letting in any air: then take away your finger, and the quickſilver will remain ſuſpended in the tube 29½ inches above its ſurface in the veſſel; ſometimes more and at other times leſs, as the weight of the air is varied by winds and other cauſes. That the quickſilver is kept up in the tube by the preſſure is evident; for if the baſon and tube be put under a glaſs, and the air be then taken out of the glaſs, all the quickſilver in the tube will fall down into the baſon, and if the air be let in again, the quickſilver will riſe to the ſame height as before. Therefore the air's preſſure on the ſurface of the earth, is equal to the weight of 29½ inches depth of quickſilver all over the earth's ſurface, at a mean rate.

A ſquare column of quickſilver, 29½ inches high, and an inch thick, weighs juſt 15 pounds, which is equal to the preſſure of the air upon every ſquare inch of the earth's ſurface; and 144 times as much, or 2160 pounds upon every ſquare foot, contains 144 ſquare inches. At this rate a middle-ſized man, whoſe ſurface may be about 14 ſquare feet, ſuſtains a preſſure of 30240 pounds when

when the air is of a mean gravity; a preſſure which would be inſupportable and fatal to us, were it not equal on every part, and counterbalanced by the ſpring of the air within us, which is diffuſed through the whole body, and re-acts with an equal force againſt the outward preſſure.

Now, ſince the earth's ſurface contains 200,000,000 ſquare miles, and every ſquare mile 27,876,400 ſquare feet, there muſt be 5,575,680,000,000,000 ſquare feet on the earth's ſurface; which number multiplied by 2160 pounds (the preſſure on each ſquare foot) gives 12,043,468,800,000,000,000 pounds for the preſſure or weight of the whole atmoſphere.

When the end of a pipe is immerſed in water, and the air is taken out of the pipe, the water will riſe in it to the height of 33 feet above the ſurface of the water in which it is immerſed; but will go no higher: for it is found, that a common pump will draw water no higher than 33 feet above the ſurface of the well; and unleſs the bucket goes within that diſtance from the well, the water will never get above it. Now, as it is the preſſure of the atmoſphere on the ſurface of the water in the well that cauſes the water to aſcend in the pump, and follow the piſton or bucket when the air above it is lifted up, it is evident, that a column of water 33 feet high is equal in weight to a column of quickſilver of the ſame diameter, 29½ inches high; and to as thick a column of air, reaching from the earth's ſurface to the top of the atmoſphere.

In ſerene calm weather, the air has weight enough to ſupport a column 31 inches high; but in tempeſtuous ſtormy weather, not above 28 inches. The quickſilver

ver thus ſupported in a glaſs tube, is found to be a nice counterbalance to the weight or preſſure of the air, and to ſhew its alterations at different times. And being now generally uſed to denote the changes in the weight of the air, and of the weather conſequent upon them, it is called the *barometer*, or weather-glaſs. — See the conſtruction and uſe of the barometer, p. 129 of the Introduction of Uſeful Knowledge.

The preſſure of the air being equal on all ſides of a body expoſed to it, the ſofteſt bodies ſuſtain this preſſure without ſuffering any change in their figure; and ſo do the moſt brittle bodies without being broke.

The air is rarefied, or made to ſwell with heat; and of this property, wind is a neceſſary conſequence. For when any part of the air is heated by the ſun, or otherwiſe, it will ſwell, and thereby affect the adjacent air; and ſo, by various degrees of heat in different places, there will ariſe various winds.

When the air is much heated, it will aſcend towards the upper part of the atmoſphere, and the adjacent air will ruſh in to ſupply its place; and therefore, there will be a ſtream or current of air from all parts towards the place where the heat is. And hence we ſee the reaſon why the air ruſhes with ſuch force into any place where a great fire is made. And alſo, why ſmoke is carried up a chimney, and why the air ruſhes in at the key-hole of the door, or any ſmall chink, when there is a fire in the room. So we may take it in general, that the air will preſs towards that part of the world where it is moſt heated.

Upon

Upon this principle we can eaſily account for the *trade-winds*, which blow conſtantly from eaſt to weſt about the equator; for, when the ſun ſhines perpendicularly on any part of the earth, it will heat the air very much in that part, which air will therefore riſe upward, and when the ſun withdraws, the adjacent air will ruſh in to fill its place; and conſequently will cauſe a ſtream or current of air from all parts towards that which is moſt heated by the ſun. But as the ſun, with reſpect to the earth, moves from eaſt to weſt, the common courſe of the air will be that way too; continually preſſing after the ſun; and therefore, at the equator, where the ſun ſhines ſtrongly, there will be a continual wind from the eaſt; but on the north ſide, it will incline a little to the north, and on the ſouth ſide to the ſouth.

This general courſe of wind about the equator, is changed in ſeveral places, and upon ſeveral accounts; as, 1. By exhalations that riſe out of the earth at certain times, and from certain places; in earthquakes and volcanoes. 2. By the falling of great quantities of rain, cauſing thereby a ſudden condenſation or contraction of the air. 3. By burning ſands, that often retain the ſolar heat to a degree incredible to thoſe who have not felt it, cauſing a more than ordinary rarefaction of the air contiguous to them. 4. By high mountains, which alter the direction of the winds in ſtriking againſt them. 5. By the declination of the ſun towards the north or ſouth, heating the air on the north or ſouth ſide the equator.

To theſe and ſuch cauſes are owing, 1. The irregularity or uncertainty of winds in climates diſtant from the equator, as in moſt parts of Europe. 2. Theſe periodical winds

winds called *Monſoons*, which in the Indian ſeas blow half a year one way, and half a year another. 3. Thoſe winds which on the coaſt of Guinea, and on the weſtern coaſts of America, blow always from weſt to eaſt. 4. The ſea breezes, which, in hot countries, blow generally from ſea to land, in the day time; and the land breezes, which blow in the night; and, in ſhort, all thoſe ſtorms, hurricanes, whirlwinds, and irregularities, which happen at different times and places.

The Monſoons.

All common air is impregnated with a certain kind of vivifying ſpirit or quality, which is neceſſary to continue the lives of animals: and this, in a gallon of air, is ſufficient for one man during the ſpace of a minute, and not much longer.

The vivifying ſpirit air.

The ſpirit in air is deſtroyed in paſſing through the lungs of animals: and hence it is, that an animal dies ſoon after being put under a veſſel which admits no freſh air to come to it. This ſpirit is alſo in the air which is in water; for fiſh die when they are excluded from freſh air, as in a pond that is cloſely frozen over: and the little eggs of inſects ſtopped up in a glaſs, do not produce their young though aſſiſted by a kindly warmth. The ſeeds alſo of plants mixed with good earth, and incloſed in a glaſs, will not grow.

This enlivening quality in air is alſo deſtroyed by the air's paſſing through fire; particularly charcoal fire, or the flame of ſulphur. Hence ſmoking chimneys muſt be very unwholeſome, eſpecially if the rooms they are in be ſmall and cloſe.

Air is alſo vitiated, by remaining cloſely pent up in any place for a conſiderable time; or perhaps, by being mixed with malignant ſteams and particles flowing from the neighbouring bodies: or laſtly, by the corruption of the vivifying ſpirit; as in holds of ſhips, in oil ciſterns, or wine cellars, which have been ſhut for a conſiderable time. The air in any of them is ſometimes ſo much vitiated, as to be immediate death to any animal that comes into it.

Damps. Air that has loſt its vivifying ſpirit is called damp, not only becauſe it is filled with humid or moiſt vapours but becauſe it deadens fire, extinguiſhes flame, and deſtroys life. The dreadful effects of damps are ſufficiently known to ſuch as work in mines.

If part of the vivifying ſpirit in air in any country begins to putrefy, the inhabitants of that country will be ſubject to an epidemical diſeaſe, which will continue until the putrefaction is over. And as the putrefying ſpirit occaſions this diſeaſe, ſo if the diſeaſed body contributes towards the putrefying of the air, then the diſeaſe will not only be epidemical, but peſtilential and contagious.

The atmoſphere is the common receptacle of all the effluvia or vapours ariſing from different bodies; of the ſteams and ſmoke of things burnt or melted; the fogs or vapours proceeding from damp watery places; and of the effluvia proceeding from ſulphureous, nitrous, acid, and alkaline bodies. In ſhort, whatever may be called volatile, riſes in air to greater or leſſer heights, according to its ſpecific gravity.

When

When the effluvia which ariſe from acid and alkaline bodies meet each other in the air, there will be a ſtrong conflict or fermentation between them; which will ſometimes be ſo great as to produce a fire; then if the effluvia be combuſtible, the fire will run from one part to another, juſt as the inflammable matter happens to lie. Fermentations.

Any one may be convinced of this, by mixing an acid and an alkaline fluid together, as Glauber's ſpirit of nitre and oil of cloves; upon the doing of which, a ſudden ferment, with a fine flame, will ariſe; and if the ingredients be very pure and ſtrong, there will be a ſudden exploſion.

Whoever conſiders the effects of fermentation, cannot be at a loſs to account for the dreadful effects of thunder and lightning; for the effluvia of ſulphureous and nitrous bodies, and others that may riſe into the atmoſphere, will ferment with each other, and take fire very often of themſelves; ſometimes by the aſſiſtance of the ſun's heat. Thunder and lightning.

If the inflammable matter be thin and light, it will riſe to the upper part of the atmoſphere, where it will flaſh without doing any harm: but if it be denſe, it will lie nearer the ſurface of the earth, where taking fire, it will explode with a ſurprizing force: and by its heat rarefy and drive away the air, kill men and cattle, ſplit trees, walls, rocks, &c. and be accompanied with terrible claps of thunder.

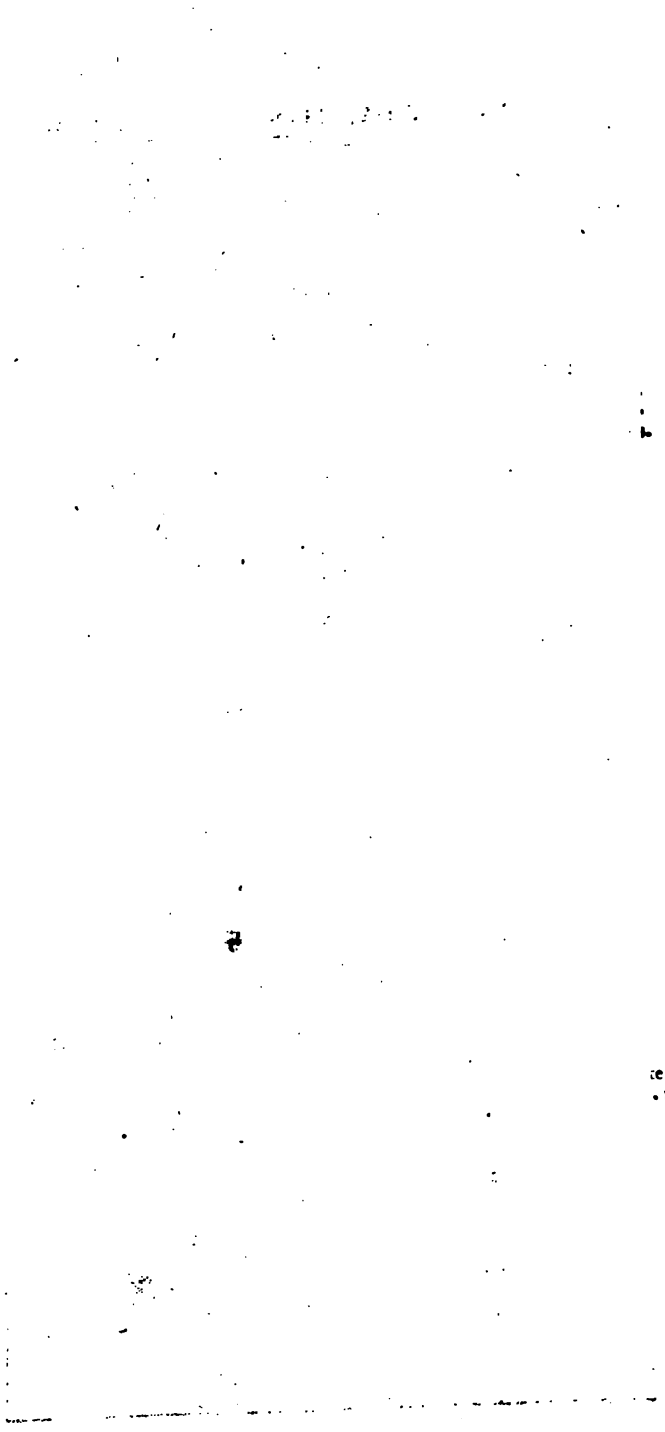
The heat of lightning appears to be quite different from that of other fires; for it has been known to run through wood, leather, cloth, &c. without hurting them,

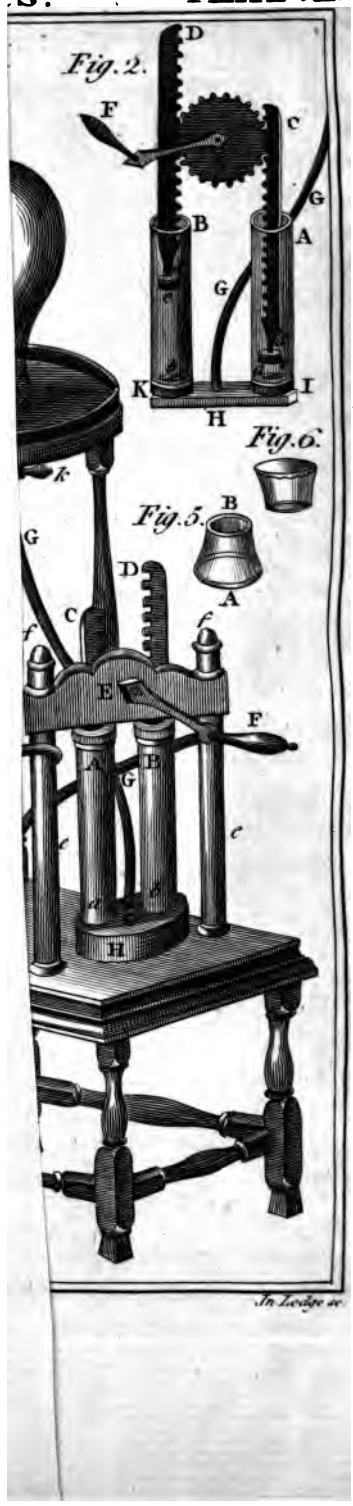
while it has broken and melted iron, ſteel, ſilver, gold, and other hard bodies. Thus it has melted or burnt aſunder a ſword, without hurting the ſcabbard; and money in a man's pocket, without hurting his clothes. The reaſon of this ſeems to be, that the particles of that fire are ſo fine, as to paſs through ſoft, looſe bodies, without diſſolving them, whilſt they ſpend their whole force upon the hard ones.

It is remarkable, that knives and forks which have been ſtruck with lightning have a very ſtrong magnetical virtue for ſeveral years after: and I have heard that lightning ſtriking upon the mariner's compaſs, will ſometimes turn it round; and often make it ſtand the contrary way, or with the north pole towards the ſouth.

Fire damps. Much of the ſame kind with lightning are thoſe exploſions, called fulminating or fire-damps, which ſometimes happen in mines; and are occaſioned by ſulphureous and nitrous, or rather oleaginous particles, riſing from the mine and mixing with the air, where they will take fire by the lights the workmen are obliged to make uſe of. The fire being kindled, will run from one part of the mine to another, like a train of gunpowder, as the combuſtible matter happens to lie; and as the elaſticity of the air is increaſed by that heat, *that* in the mine will conſequently ſwell very much, and ſo, for want of room will explode with a greater or leſs degree of force, according to the denſity of the combuſtible vapours. It is ſometimes ſo ſtrong, as to blow up the mine; and at other times ſo weak, that when it has taken fire at the flame of a candle, it is eaſily blown out.

Air that will take fire at the flame of a candle, may be produced thus: Having exhauſted a receiver of the





Fire

the air-pump, let the air run into it through the flame of the oil of turpentine; then remove the cover of the receiver, and holding a candle to that air, it will take fire, and burn quicker or ſlower, according to the denſity of the oleaginous vapour.

When ſuch combuſtible matter, as is above mentioned, kindles in the bowels of the earth, where there is little or no vent, it produces earthquakes, and violent ſtorms or hurricanes of wind when it breaks forth in the air. Earthquakes.

An artificial earthquake may be made thus: Take 10 or 15 pounds of ſulphur, and as much of the filings of iron, and knead them with common water into the conſiſtency of a paſte; this being buried in the ground, will, in 8 or 10 hours time, burſt out into flames, and cauſe the earth to tremble all around to a conſiderable diſtance.

From this experiment we have a very natural account of the fires of Mount Ætna, Veſuvius, and other volcanoes, they being probably ſet on fire at firſt by the mixture of ſuch metalline and ſulphureous particles.

The air-pump being conſtructed the ſame way as the water-pump, whoever underſtands the one, will be at no loſs to underſtand the other. Plate VII. Fig. 1.

Having put a wet leather on the plate L L of the air-pump, place the glaſs receiver M upon the leather, ſo that the hole i in the plate, may be within the glaſs; then turning the handle F backward and forward, the air will be pumped out of the receiver; which will then be held down to the plate by the preſſure of the external air,

or

or atmoſphere. For, as the handle F (Fig. 2.) is turned backwards, it raiſes the piſton d e in the barrel; B K, by means of the wheel E and rack D d: and, as the piſton is leathered ſo tight as to fit the barrel exactly, no air can get between the piſton and barrel; and therefore all the air above d in the barrel is lifted up towards B, and a vacuum is made in the barrel from b to e; upon which, part of the air in the receiver M (Fig. 1.) by its ſpring, ruſhes through the hole i, in the braſs plate L L, along the pipe G C G (which communicates with both barrels in the hollow trunk I H K, Fig. 2.) and puſhing up the valve b, enters into the vacant place b e of the barrel B K. For, wherever the reſiſtance or preſſure is taken off, the air will run to that place, if it can find a paſſage. Then if the handle F be turned forward, the piſton d e will be depreſſed in the barrel; and, as the air which had got into the barrel cannot be puſhed back through the valve b, it will aſcend through a hole in the piſton, and eſcape through a valve at d; and be hindered by that valve from returning into the barrel when the piſton is again raiſed. At the next raiſing of the piſton, a vacuum is again made in the ſame manner as before, between b and e; upon which more of the air that was left in the receiver M, gets out thence by its ſpring, and runs into the barrel B K, through the valve B. The ſame thing is to be underſtood with regard to the other barrel A I; and as the handle F is turned backwards and forwards, it alternately raiſes and depreſſes the piſtons in their barrels; always raiſing one while it depreſſes the other. And, as there is a vacuum made in each barrel when its piſton is raiſed, the particles of air in the receiver M, puſh out another, by their ſpring or elaſticity, through the hole i, and pipe G G into the barrels; until at laſt the air in the

the receiver comes to be ſo much dilated, and its ſpring ſo far weakened, that it can no longer get through the valves; and then no more can be taken out. Hence, there is no ſuch thing as making a perfect vacuum in the receiver; for the quantity of air taken out at any one ſtroke, will always be as the denſity thereof in the receiver; therefore it is impoſſible to take it all out, becauſe, ſuppoſing the receiver and barrels of equal capacity, there will be always as much left as was taken out at the laſt turn of the handle.

There is a cock k below the pump-plate, which being turned, lets the air into the receiver again; and then the receiver becomes looſe, and may be taken off the plate. The barrels are fixed to the frame E e e by two ſcrew-nuts f f, which preſs down the top-piece E upon the barrels: and the hollow trunk H (in Fig. 2.) is covered by a box, as G H (in Fig. 1.)

There is a glaſs tube, l m m m n, open at both ends, and about 34 inches long; the upper end communicating with the hole in the pump-plate, and the lower end immerſed in quickſilver at n in the veſſel N. To this tube is fitted a wooden ruler m m, called the gauge which is divided into inches and parts of an inch, from the bottom at n (where it is even with the ſurface of the quickſilver) and continued up to the top, a little below l, to 30 or 31 inches.

As the air is pumped out of the receiver M, it is likewiſe pumped out of the tube l m n, becauſe that tube opens into the receiver through the pump-plate; and as the tube is gradually emptied of air, the quickſilver in the veſſel N is forced up into the tube by the preſſure of the

the atmoſphere. And if the receiver could be perfectly exhauſted of air, the quickſilver would ſtand as high in the tube as it does at that time in the barometer: for it is ſupported by the ſame power or weight of the atmoſphere in both.

The quantity of air exhauſted out of the receiver on each turn of the handle, is always proportionable to the aſcent of the quickſilver on that turn: and the quantity of air remaining in the receiver, is proportionable to the defect of the height of the quickſilver in the gauge, from what it is at that time in the barometer.

I ſhall now give an account of the experiments made with the air-pump; ſhewing the reſiſtance, weight, and elaſticity of the air.

To ſhew the reſiſtance of the air. There is a little machine, conſiſting of two mills, a and b, which are of equal weights, independent of each other, and turn equally free on their axles in the frame. Each mill has four thin arms or ſails fixed into the axis: thoſe of the mill a have their planes at right angles to its axis, and thoſe of b have their planes parallel to it. Therefore, as the mill a turns round in common air, it is but little reſiſted thereby, becauſe its ſails cut the air with their thin edges: but the mill b is much reſiſted, becauſe the broad ſide of its ſails move againſt the air when it turns round. In each axle is a fine pin near the middle of the frame, which goes quite through the axle, and ſtands out a little on each ſide of it: under theſe pins the ſlider a may be made to bear, and ſo hinder the mills from going, when the ſtrong ſpring C is ſet on bend againſt the oppoſite ends of the pins.

Having

Having ſet this machine upon the pump-plate L L (fig. 1.) draw up the ſlider d to the pins on one ſide, and ſet the ſpring C at bend on the oppoſite ends of the pins: then puſh down the ſlider d, and the ſpring acting equally ſtrong upon each mill, will ſet them both a going with equal forces and velocities; but the mill a, will run much longer than the mill b, becauſe the air makes much leſs reſiſtance againſt the edges of its ſails than againſt the ſides of the ſails of b.

Draw up the ſlider again, and ſet the ſpring upon the pins as before; then cover the machine with the receiver M upon the pump-plate; and having exhauſted the receiver of air, puſh down the wire P P (thro' the collar of leathers in the neck g) upon the ſlider; which will diſengage it from the pins, and allow the mills to turn round by the impulſe of the ſpring: and as there is no air in the receiver to make any ſenſible reſiſtance againſt them, they will both move a conſiderable time longer than they did in the open air; and the moment that one ſtops the other will do ſo too. This ſhews that air reſiſts bodies in motion, and that equal bodies meet with different degrees of reſiſtance, according as they preſent greater or leſs ſurfaces to the air in the planes of their motions. Fig. 11

Take off the receiver M, and the mills; and having put the guinea a and feather b upon the braſs flap c, turn up the flap and ſhut it into the notch d. Then, putting a wet leather over the top of the tall receiver A B (it being open both at top and bottom, cover it with the plate C, from which the guinea and feather tongs e d will then hang within the receiver. This done, pump the air out Experiment II. Fig. 4.

of the receiver; and then draw up the wire f a little, which by a ſquare piece on its lower end, will open the tongs e d; and the flap falling down as at c, the guinea and feather will deſcend with equal velocities in the receiver; and both will fall upon the pump-plate at the ſame inſtant.

In this experiment the obſervers ought not to look at the top, but at the bottom of the receiver, in order to ſee the guinea and feather fall upon the plate; otherwiſe, on account of the quickneſs of their motion, they will eſcape the ſight of the beholders.

To ſhew the Weight of the Air.

Experiment III.

HAVING fitted a braſs cap, with a valve tied over it, to the mouth of a thin bottle or Florence flaſk, whoſe contents are exactly known, ſcrew the neck of this cap into the hole i of the pump-plate: then having exhauſted the air out of the flaſk, and taken it off the pump, let it be ſuſpended at one end of a balance, and nicely counterpoiſed by weights in the ſcale at the other end: this done, raiſe up the valve with a pin, and the air will ruſh into the flaſk with an audible noiſe; during which time the flaſk will deſcend, and pull down that end of the beam. When the noiſe is over, put as many grains into the ſcale, at the other end, as reſtore the equilibrium; and they will ſhew exactly the weight of the quantity of air that has got into the flaſk, and filled it. If the flaſk holds an exact quart, it will be found, that 16 grains will reſtore the equipoiſe of the balance when the quickſilver ſtands at 29½ inches in the barometer; which ſhews, that when the air is at a mean rate of denſity, a quart of it

it weighs 16 grains: it weighs more when the quickſilver ſtands higher; and leſs when it ſtands lower.

Place the ſmall receiver O (fig. 1.) over the hole i in the pump-plate, and upon exhauſting the air, the receiver will be fixed down to the plate by the preſſure of the air on its outſide, which is left to act alone, without any air in the receiver to act againſt it: and this preſſure will be equal to as many times 15 pounds as there are ſquare inches in that part of the plate which the receiver covers; which will hold down the receiver ſo faſt, that it cannot be got off until the air be let into it by turning the cock k; and then it becomes looſe. Experiment IV.

Set the little glaſs A B (which is open at both ends) over the hole i upon the pump-plate L L, and put your hand cloſe upon the top of it at B: then upon exhauſting the air out of the glaſs, you will find your hand preſſed down with a great weight upon it: ſo that you can hardly releaſe it until the air be re-admitted into the glaſs by turning the cock k; which air, by acting as ſtrongly upward againſt the hand as the external air acted in preſſing it downward, will releaſe the hand from its confinement. Experiment V. Fig. 5.

Having tied a piece of wet bladder b over the open top of the glaſs A (which is alſo open at bottom) ſet it to dry, and then the bladder will be tight like a drum. Then place the open plate A upon the pump-plate, over the hole i, and begin to exhauſt the air out of the glaſs. As the air is exhauſting, its ſpring in the glaſs will be weakened, and give way to the preſſure of the outward air on the bladder; which, as it is preſſed down, will put Experiment VI. Fig. 6.

on a ſpherical concave figure, which will grow deeper and deeper, until the ſtrength of the bladder be overcome by the weight of the air; and then it will break with a report as loud as that of a gun. If a flat piece of glaſs be laid upon the top of this receiver, and joined to it by a flat ring of wet leather between them, upon pumping the air out of the receiver, the preſſure of the outward air upon the flat glaſs will break it all to pieces.

Experiment VII. Plate VIII. Fig. 1. Pour ſome quickſilver into the jar D, and ſet it on the pump-plate near the hole i; then ſet on the tall open receiver A B, ſo as to be over the jar and hole; and cover the receiver with the braſs plate C. Screw the open glaſs tube f g, which has a braſs top on it at h, into the ſyringe H, and, putting the tube through a hole in the middle of the plate, ſo as to immerſe the lower end of the tube e into the quickſilver at D, ſcrew the end h of the ſyringe into the plate. This done, draw up the piſton in the ſyringe by the ring I, which will make a vacuum in the ſyringe below the piſton: and as the upper end of the tube opens into the ſyringe, the air will be dilated in the tube, becauſe part of it, by its ſpring, gets up to the ſyringe; and the ſpring of the undilated air in the receiver acting upon the ſurface of the quickſilver in the jar, will force part of it up into the tube: for the quickſilver will follow the piſton in the ſyringe, in the ſame way, and for the ſame reaſon, that water follows the piſton of a common pump when it is raiſed in the pump-barrel; and this, according to ſome, is done by ſuction. But to refute that erroneous notion, let the air be pumped out of the receiver A B, and then all the quickſilver in the tube will fall down by its own weight into the jar; and cannot be raiſed one hair's breadth in the tube by working the ſyringe; which ſhews that ſuction had no hand in raiſing the quickſilver: and to prove that it is done

Exp
Plat
Fig.

PLATE VIII

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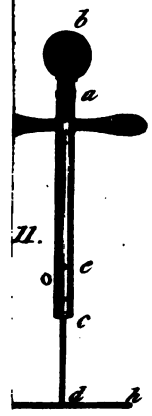

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done by preſſure, let the air into the receiver by the cock k (Plate VII. fig. 1.) and its action upon the ſurface of the quickſilver in the jar will raiſe it up into the tube, although the piſton of the ſyringe continues motionleſs. If the tube be about 32 or 33 inches high, the quickſilver will riſe in it very near as high as it ſtands at that time in the barometer. And, if the ſyringe has a ſmall hole, as m, near the top of it, and the piſton be drawn up above that hole, the air will ruſh thro' the hole into the ſyringe and tube, and the quickſilver will immediately fall down into the jar. If this part of the apparatus be air-tight, the quickſilver may be pumped up into the tube to the ſame height that it ſtands in the barometer; but it will go no higher, becauſe then the weight of the column in the tube is the ſame as the weight of a column of air, of the ſame thickneſs with the quickſilver, and reaching from the earth to the top of the atmoſphere.

Experiment VIII. Fig. 2.

Having placed the jar A, with ſome quickſilver in it, on the pump-plate, as in the laſt experiment, cover it with the receiver B, then puſh the open end of the glaſs tube d e through the collar of leathers in the braſs neck C (which it fits ſo as to be air-tight) almoſt down to the quickſilver in the jar; then exhauſt the air out of the receiver, and it will alſo come out of the tube, becauſe the tube is cloſe at top. When the gauge m m ſhews that the receiver is well exhauſted, puſh the tube, ſo as to immerſe its lower end into the quickſilver in the jar. Now, although the tube be exhauſted of air, none of the quickſilver will riſe into it, becauſe there is no air left in the receiver to preſs upon its ſurface in the jar. But let the air into the receiver by the cock k, and the quickſilver

ver will immediately riſe in the tube, and ſtand as high in it as it was pumped up in the laſt experiment.

Both theſe experiments ſhew that the quickſilver is ſupported in the barometer by the preſſure of the air on its ſurface in the box, in which the open end of the tube is placed; and that the more denſe and heavy the air is, the higher the quickſilver riſes; and, on the contrary, the thinner and lighter the air is, the more will the quickſilver fall; for if the handle F be turned ever ſo little, it takes ſome air out of the receiver, by raiſing one or other of the piſtons in its barrel; and conſequently, that which remains in the quickſilver is ſo much the rarer, and has ſo much the leſs ſpring and weight; and thereupon the quickſilver falls a little in the tube: but upon turning the cock, and re-admitting the air into the receiver, it becomes as weighty as before, and the quickſilver riſes again to the ſame height. Thus we ſee the reaſon why the quickſilver in the barometer falls before rain or ſnow, and riſes before fair weather; for in the former caſe the air is too thin and light to bear up the vapours; and in the latter, too denſe and heavy to let them fall.

It is to be noted, that, in all mercurial experiments with the air-pump, a ſhort pipe muſt be ſcrewed into the hole i, ſo as to riſe about an inch above the plate, to prevent the quickſilver from getting into the air-pipe and barrels, in caſe any of it ſhould be accidentally ſpilt over the jar; for if it once gets into the pipes or barrels, it ſpoils them, by looſening the ſolder, and corroding the braſs.

Take

Take the tube out of the receiver, and put one end of a bit of dry hazel branch, about an inch long, tight into the hole, and the other end tight into a hole quite thro' the bottom of a ſmall wooden cup; then pour ſome quickſilver into the cup, and exhauſt the receiver of air, and the preſſure of the outward air, on the ſurface of the quickſilver, will force it thro' the pores of the hazel, from whence it will deſcend in a beautiful ſhower, into a glaſs cup placed under the receiver to catch it. Experiment IX.

Put a wire through the collar of leathers on the top of the receiver, and fix a bit of dry wood on the end of the wire within the receiver; then exhauſt the air, and puſh the wire down ſo as to immerſe the wood into a jar of quick-ſilver on the pump-plate; this done, let in the air, and upon taking the wood out of the jar and ſplitting it, its pores will be found full of quickſilver, which the force of the air, upon being let into the quickſilver, drove into the wood. Experiment X.

Join the two braſs hemiſpherical cups A and B together, with a wet leather between them, having a hole in the middle of it; then ſcrew the end D of the pipe C D into the plate of the pump at i, and turn the cock E, ſo as the pipe may be open all the way into the cavity of the hemiſpheres: then exhauſt the air out of them, and turn the cock a quarter round, which will ſhut the pipe C D and keep out the air. This done, unſcrew the pipe at D from the pump, and ſcrew the piece F h upon it at D; and let two ſtrong men try to pull the hemiſpheres aſunder by the rings g and h, which they will find hard to do; for if the diameter of the hemiſpheres be four inches, they will be preſſed together by the external air with a force equal to 190 pounds: and to ſhew that it is the preſſure Experiment XI. Plate VII. Fig. 7.

preſſure of the air that keeps them together, hang them by either of the rings upon the hook P of the wire in the receiver M (Fig. 1.) and, upon exhauſting the air out of the receiver, they will fall aſunder of themſelves.

Experiment XII. Place a ſmall receiver O (Fig. 1.) near the hole i on the pump-plate, and cover both it and the hole with the receiver M; and turn the wire ſo by the top P, that its hook may take hold of the little receiver by a ring at its top, allowing that receiver to ſtand with its own weight on the plate. Then, upon working the pump, the air will come out of both receivers; but the large one M, will be forcibly held down to the pump by the preſſure of the external air; whilſt the ſmall one O, having no air to preſs upon it, will continue looſe, and may be drawn up and let down at pleaſure by the wire P P. But upon letting it quite down to the plate, and admitting the air into the receiver M, by the cock k, the air will preſs ſo ſtrongly upon the ſmall receiver O, as to fix it down to the plate; and, at the ſame time, by counterbalancing the outward preſſure on the large receiver M, it will become looſe. This experiment evidently ſhews, that the receivers are held down by preſſure, and not by ſuction, for the internal receiver continued looſe while the operator was pumping, and the external one was held down; but the former became faſt immediately by letting in the air upon it.

Plate VIII. Fig. 3. Experiment XIII. Screw the end A of the braſs pipe ABF into the pump-plate, and turn the cock e until the pipe be open; then put a wet leather on the plate c d (fixed on the pipe) and cover it with the tall receiver G H, which is cloſe at top; then exhauſt the air out of the receiver, and turn the cock e

to

to keep it out; which done, unſcrew the pipe from the pump, and ſet its end A into a baſon of water, and turn the cock e to open the pipe; on which, as there is no air in the receiver, the preſſure of the atmoſphere on the water in the baſon, will drive the water forcibly thro' the pipe, and make it play up in a jet to the top of the receiver.

Set the ſquare phial A upon the pump-plate, and having covered it with the wire cage B, put a cloſe receiver over it, and exhauſt the air out of the receiver; in doing which, the air will alſo make its way out of the phial, through a ſmall hole in its neck under the valve b. When the air is exhauſted, turn the cock below the plate to re-admit the air into the receiver; and as it cannot get into the phial again, becauſe of the valve, the phial will be broke into ſome thouſands of pieces by the preſſure of the air upon it. Had the phial been of a round form, it would have ſuſtained this preſſure like an arch, without breaking; but as its ſides are flat, it cannot. Plate VII. Fig. 8. Experiment XIV.

To ſhew the elaſticity or ſpring of the air. Tie up a very ſmall quantity of air in a bladder, and put it under the receiver: then exhauſt the air out of the receiver; and the ſmall quantity which is confined in the bladder (having nothing to act againſt it) will expand itſelf ſo by the force of its ſpring, as to fill the bladder as full as it could be blown of common air. But upon letting the air into the receiver again, it will overpower the air in the bladder, and preſs its ſides almoſt cloſe together. Experiment XV. Fig. 11.

If the bladder ſo tied up be put into a wooden box, and have 20 or 30 pounds weight of lead put upon it in the box, and the box be covered with a cloſe receiver; Experiment XVI.

upon exhauſting the air out of the receiver, that air which is confined in the bladder will expand itſelf ſo as to raiſe up all the lead by the force of its ſpring.

Plate VIII. Fig. 3. Exp. 17. Screw the pipe A B into the pump-plate, place the tall receiver G H upon the plate c d, as in the 13th experiment, and exhauſt the air out of the receiver; then turn the cock e to keep out the air, unſcrew the pipe from the pump, and ſcrew it into the mouth of the copper veſſel C C (Fig. 4.) the veſſel having been firſt about half filled with water. Then open the cock e (Fig. 3.) and the ſpring of the air which is confined in the copper veſſel will force the water up thro' the pipe A B in a jet into the exhauſted receiver, as ſtrongly as it did by its preſſure on the ſurface of the water in a baſon, in the thirteenth experiment.

Exp. 18. If a fowl, cat, rat, mouſe, or bird, be put under a receiver, and the air be exhauſted, the animal will be at firſt oppreſſed as with a great weight, then grow convulſed, and at laſt expire in all the agonies of a moſt bitter and cruel death. But as this experiment is too ſhocking to every ſpectator who has the leaſt degree of humanity, we ſubſtitute a machine called the *lungs-glaſs*, in place of the animal.

Exp. 19. If a butterfly be ſuſpended in a receiver, by a fine thread tied to one of its horns, it will fly about in the receiver, as long as the receiver continues full of air; but if the air be exhauſted, tho' the animal will not die, and will continue to flutter its wings, it cannot remove itſelf from the place where it hangs, in the middle of the receiver, until the air be let in again, and then the animal will fly about as before.

Pour

Pour ſome quickſilver into the ſmall bottle A, and ſcrew the braſs collar c of the tube B C into the braſs neck b of the bottle, and the lower end of the tube will be immerſed into the quickſilver, ſo that the air above the quickſilver in the bottle will be confined there, becauſe it cannot get about the joining, nor can it be drawn out thro' the quickſilver into the tube. This tube is alſo open at top, and is to be covered with the receiver G and large tube E F; which tube is fixed by braſs collars to the receiver, and is cloſe at the top. This preparation being made, exhauſt the air both out of the receiver and its tube; and the air will by the ſame means be exhauſted out of the inner tube B C thro' its open top at C; and as the receiver and tubes are exhauſting, the air that is confined in the glaſs bottle A will preſs ſo by its ſpring on the ſurface of the quickſilver, as to force it up in the inner tube as high as it was raiſed in the tenth experiment by the preſſure of the atmoſphere: which demonſtrates that the ſpring of the air is equivalent to its weight. Exp. 20. Fig. 5.

Put a cork into the ſquare phial A, and fix it in with wax or cement; put the phial on the pump-plate with the wire cage B over it, and cover the cage with a cloſe receiver; then exhauſt the air out of the receiver, and the air that was corked up in the phial will break the phial outwards by the force of its ſpring, becauſe there is no air left on the outſide of the phial to act againſt the air within it. Exp. 21. Plate VII. Fig. 8.

Put a ſhrivelled apple under a cloſe receiver, and exhauſt the air; then the ſpring of the air within the apple will plump it out, ſo as to cauſe all the wrinkles to diſappear; but upon letting the air into the receiver again, to preſs upon the apple, it will inſtantly return to its former decayed and ſhrivelled ſtate. Exp. 22.

Exp. 23. Take a freſh egg, and cut off a little of the ſhell and film from its ſmalleſt end, then put the egg under a receiver, and pump out the air; upon which all the contents of the egg will be forced out into the receiver, by the expanſion of a ſmall bubble of air contained in the great end, between the ſhell and film.

Exp. 24. Put ſome warm beer into a glaſs, and having ſet it on the pump, cover it with a cloſe receiver, and then exhauſt the air. Whilſt this is doing, and thereby the preſſure more and more taken off from the beer in the glaſs, the air therein will expand itſelf, and riſe up in innumerable bubbles to the ſurface of the beer; and from thence it will be taken away with the other air in the receiver. When the receiver is nearly exhauſted, the air in the beer, which could not diſentangle itſelf quick enough to get off with the reſt, will now expand itſelf ſo, as to cauſe the beer to have all the appearance of boiling; and the greateſt part of it will go over the glaſs.

Exp. 25. Put ſome warm water into a glaſs, and put a bit of dry wainſcot or other wood into the water; then cover the glaſs with a cloſe receiver, and exhauſt the air; upon which the air in the wood having liberty to expand itſelf, will come out plentifully, and make all the water to bubble about the wood, eſpecially about the ends, becauſe the pores lie lengthways. A cubic inch of dry wainſcot has ſo much air in it, that it will continue bubbling for near half an hour together.

Miſcellaneous Experiments.

SCREW the ſyringe H (fig. 1.) to a piece of lead that weighs one pound at leaſt; and, holding the lead in one hand, pull up the piſton in the ſyringe with the other; then quitting hold of the lead, the air will puſh it upward, and drive back the ſyringe upon the piſton. The reaſon of this is, that the drawing up of the piſton makes a vacuum in the ſyringe, and the air which preſſes every way equally, having nothing to reſiſt its preſſure upward, the lead is thereby preſſed upward, contrary to its natural tendency by gravity. If the ſyringe, ſo loaded, be hung in a receiver, and the air be exhauſted, the ſyringe and lead will deſcend upon the piſton-rod by their natural gravity; and, upon admitting the air into the receiver, they will be driven upward again, until the piſton be at the very bottom of the ſyringe. Exp. 26. Plate VIII.

Let a large piece of cork be ſuſpended by a thread at one end of a balance, and counterpoiſed by a leaden weight, ſuſpended in the ſame manner, at the other. Let this balance be hung to the inſide of the top of a large receiver; which being ſet on the pump, and the air exhauſted, the cork will preponderate, and ſhew itſelf to be heavier than the lead; but upon letting in the air again, the equilibrium will be reſtored. The reaſon of this is, that ſince the air is a fluid, and all bodies loſe as much of their abſolute weight in it as is equal to the weight of their bulk of the fluid, the cork being the larger body, loſes more of its real weight than the lead does; and therefore muſt in fact be heavier, to balance it under the diſadvantage of loſing ſome of its weight, which Exp. 27.

which diſadvantge being taken off by removing the air, the bodies then gravitate according to their real quantities of matter, and the cork which balanced the lead in air, ſhews itſelf to be heavier when in vacuo.

Exp. 28. Set a lighted candle upon the pump, and cover it with a tall receiver. If the receiver holds a gallon, the candle will burn a minute; and then, after having gradually decayed from the firſt inſtant, it will go out; which ſhews that a conſtant ſupply of freſh air is neceſſary to feed flame; and ſo it alſo is for animal life; for a bird kept under a cloſe receiver will ſoon die, altho' no air be pumped out; and it is found that, in the diving bell, a gallon of air is ſufficient only for one minute for a man to breathe in.

The moment when the candle goes out, the ſmoke will be ſeen to aſcend to the top of the receiver, and there it will form a ſort of cloud; but upon exhauſting the air, the ſmoke will fall down to the bottom of the receiver, and leave it as clear at the top as it was before it was ſet upon the pump. This ſhews that ſmoke does not aſcend on account of its being poſitively light, but becauſe it is lighter than air; and its falling to the bottom when the air is taken away, ſhews that it is not deſtitute of weight. So moſt ſorts of wood aſcend or ſwim in water; and yet there are none who doubt of the wood's having gravity or weight.

Exp. 29. Set a receiver which is open at top, on the air-pump, and cover it with a braſs plate and wet leather; and having exhauſted it of air, let the air in again at top thro' an iron pipe, making it paſs thro' a charcoal flame at the end of the pipe; and when the receiver is full of that air, lift up the cover, and let down a mouſe or bird into

to the receiver, and the burnt air will immediately kill it. If a candle be let down into that air, it will go out directly; but by letting it down gently, it will purify the air ſo far as it goes; and ſo by letting it down more and more, the flame will drive out the bad air, and good air will get in.

Set a bell upon a cuſhion on the pump-plate, and cover it with a receiver; then ſhake the pump to make the clapper ſtrike againſt the bell, and the ſound will be very well heard; but, exhauſt the receiver of air, and then, if the clapper be made to ſtrike ever ſo hard againſt the bell, it will make no ſound at all; which ſhews that air is abſolutely neceſſary for the propagation of ſound. Exp. 30.

Let a candle be placed on one ſide of a receiver, and viewed thro' the receiver at ſome diſtance; then, as ſoon as the air begins to be exhauſted, the receiver will be filled with vapours, which riſe from the wet leather, by the ſpring of the air in it; and the light of the candle being refracted through that medium of vapours, will have the appearance of circles of various colours, of a faint reſemblance to thoſe of the rainbow. Exp. 31.

The air-pump was invented by *Otho Gueriche*, of *Magdeburg*; but was much improved by Mr. *Boyle*, to whom we are indebted for our greateſt part of the knowledge of the wonderful properties of the air, demonſtrated in the above experiments.

The elaſtic air which is contained in many bodies, and is kept in them by the weight of the atmoſphere, may be got out of them either by boiling, or by the air-pump,

as

as ſhewn in the 24th experiment: but the fixed air, which is by much the greater quantity, cannot be got out but by diſtillation, fermentation, or putrefaction.

If fixed air did not come out of bodies with difficulty, and ſpend ſome time in extricating itſelf from them, it would tear them to pieces. Trees would be rent by the change of air, from a fixed to an elaſtic ſtate; and animals would be burſt in pieces by the exploſion of air in their food.

Dr. *Hales* found by experiment, that the air in apples is ſo much condenſed, that if it were let out into the common air, it would fill a ſpace 48 times as great as the bulk of the apples themſelves; ſo that its preſſure outwards was equal to 11776lb.; and in a cubic inch of oak to 19860lb. againſt its ſides. So that if the air was let looſe at once in theſe ſubſtances, they would tear every thing to pieces about them, with a force ſuperior to that of gunpowder. Hence, in eating apples, it is well that they part with the air by degrees as they are chewed, and foment in the ſtomach, otherwiſe an apple would be immediate death to him who eats it.

The mixing of ſome ſubſtances with others will releaſe the air from them all of a ſudden; which may be attended with very great danger. Of this we have a remarkable inſtance in an experiment made by Dr. Slare; who, having put half a dram of oil of carraway-ſeeds into one glaſs, and a dram of compound ſpirit of nitre in another, covered them both on the air-pump with a receiver 6 inches wide, and 8 inches deep, and then exhauſted the air, and continued pumping until all that could poſſibly be got both out of the receiver and out of the two fluids, was extricated: then, by a particular

cular contrivance from the top of the receiver, he mixed the fluids together; upon which they produced ſuch a prodigious quantity of air, as inſtantly blew up the receiver, although it was preſſed down by the atmoſphere with upwards of 400 pounds weight. Obſerve in the 27th experiment, the cork muſt be covered all over with a piece of thin wet bladder glued to it, and not uſed until it be thoroughly dry.

The Conſtruction and Uſe of the Barometer, or Weather Glaſs.

THIS inſtrument is uſeful for meaſuring the weight of the atmoſphere, and in foretelling the changes of the weather, and alſo for meaſuring the height of mountains, &c. Fig. 2.

The common barometer conſiſts of a glaſs tube hermetically ſealed at one end, and filled with quickſilver, and defecated and purged of its air. The finger being then placed on the open end, in immediate contact with the mercury, ſo as not to admit the leaſt particle of air, the tube is inverted, and the lower end plunged into a baſon of the ſame prepared mercury (See Miſcellaneous Articles.) Then, upon removing the finger, the mercury in the tube will join that in the baſon, and the mercurial column in the tube will ſubſide to the height of twenty-nine or thirty inches, according to the ſtate of the atmoſphere at that time (See the Scale.) This is the principle upon which all barometers are conſtructed. Fig. 6.

In the beginning of the laſt century, philoſophers were of opinion that the aſcent of water in pumps was owing to the abhorrence of a vacuum; and, that by means of ſuction, fluids might be raiſed to any height whatever.

Galileo's discovery.

But *Galilæo*, who flouriſhed about that time, diſcovered that water would not aſcend in a pump unleſs the ſucker reached within thirty-three feet of its ſurface in the well. From hence he concluded, that not the power of ſuction, but the preſſure of the atmoſphere was the cauſe of the aſcent of water in pumps: that a column of water thirty-three feet high was a counterpoiſe to one of air of an equal baſe, whoſe height extended to the top of the atmoſphere; and that for this reaſon the water would not follow the ſucker any farther. From this, TORRICELLI, *Galilæo*'s diſciple, took the hint; and conſidered that, if a column of water of about thirty-three feet in height was equal in weight to one of air having the ſame baſe, a column of mercury no longer than about twenty-nine inches and a half would be ſo too, becauſe, mercury being about fourteen times heavier than water, a column of mercury muſt be fourteen times ſhorter than one of water equally heavy. Accordingly, having filled a glaſs tube with mercury, and inverted it into a baſon of the ſame, he found the mercury in the tube to deſcend till it ſtood about twenty-nine inches and a half above the ſurface of that in the baſon.

Torricellian experiment.

It was, however, ſome time after the Torricellian experiment had been made, and even after it had been univerſally agreed, that the ſuſpenſion of the mercury was owing to the weight of the atmoſphere, before it was diſcovered that this preſſure of the air was different at different times, though the tube was kept in the ſame place. But the variations of altitude in the mercurial columns were too obvious to remain long unobſerved: and accordingly philoſophers ſoon became careful enough to mark them. When this was done, it was impoſſible to avoid obſerving alſo, that the changes in the height of the mercury were accompanied, or very quickly ſucceeded,

ceeded, by changes in the weather. Hence, the inſtrument obtained the name of the Weather-Glaſs; and was generally made uſe of with a view to the foreknowledge of the weather. In this character, its principal phenomena are as follow:

Preliminary rules to judge of the weather.

1. The riſing of the mercury preſages, in general, fair weather; and its falling, foul weather; as rain, ſnow, high winds, and ſtorms. 2. In very hot weather, the falling of the mercury foreſhews thunder. 3. In winter, the riſing preſages froſt; and in froſty weather, if the mercury falls three or four diviſions, there will certainly follow a thaw. But in a continued froſt, if the mercury riſes, it will certainly ſnow. 4. When foul weather happens ſoon after the falling of the mercury, expect but little of it; and, on the contrary, expect but little fair weather when it proves fair ſhortly after the mercury has riſen. 5. In foul weather, when the mercury riſes much and high, and ſo continues for two or three days before the foul weather is quite over, then expect a continuance of fair weather to follow. 6. In fair weather, when the mercury falls much and low, and thus continues for two or three days before the rain comes, then expect a great deal of wet, and probably high winds. 7. The unſettled motion of the mercury denotes uncertain and changeable weather. 8. You are not ſo ſtrictly to obſerve the words engraved on the plates (though in general it will agree with them) as the mercury's riſing and falling; for if it ſtands at much rain, and then riſes up to changeable, it preſages fair weather; though not to continue ſo long as if the mercury had riſen higher: and ſo, on the contrary, if the mercury ſtood at fair, and falls to changeable, it preſages

Note.

foul weather; though not ſo much of it as if it had ſunk lower.

From theſe obſervations it appears, that it is not ſo much the height of the mercury in the tube that indicates the weather, as the motion of it up and down: wherefore, in order to paſs a right judgment of what weather is to be expected, we ought to know whether the mercury is actually riſing or falling; to which end the following rules are of uſe.

1. If the ſurface of the mercury is convex, ſtanding higher in the middle of the tube than at the ſides, it is generally a ſign that the mercury is then riſing. 2. If the ſurface is concave, it is then ſinking: and, 3. If it is plain, the mercury is ſtationary, or rather if it is a little convex; for mercury being put into a glaſs tube, eſpecially a ſmall one, will naturally have its ſurface a little convex, becauſe the particles of mercury attract one another more forcibly than they are attracted by glaſs. 4. If the glaſs is ſmall, ſhake the tube; and if the air is grown heavier, the mercury will riſe about half the tenth of an inch higher than it ſtood before: if it is grown lighter, it will ſink as much. This proceeds from the mercury's ſticking to the ſides of the tube, which prevents the free motion of it till it is diſengaged by the ſhock: and therefore when an obſervation is to be made by ſuch a tube, it ought always to be ſhaken firſt; for ſometimes the mercury will not vary of its own accord, till the weather it ought to have indicated is preſent.

Here we muſt obſerve, that the above-mentioned phenomena are peculiar to places lying a conſiderable diſtance

tance from the equator; for in the torrid zone, the mercury in the barometer ſeldom either riſes or falls much. In Jamaica, it is obſerved by Sir *William Beeſton*, that the mercury in the morning conſtantly ſtood at one degree below changeable, and at noon ſunk to one degree above rain; ſo that the whole ſcale of variation there was only three-tenths of an inch. At St. Helena, too, where Dr. *Halley* made his obſervations, he found the mercury to remain almoſt ſtationary whatever weather happened. Of theſe phenomena, their cauſes, and why the barometer indicates an approaching change of weather, the Doctor gives us the following account:

Dr. Halley's rules and obſervations.

1. In calm weather, when the air is inclined to rain, the mercury is commonly low. 2. In ſerene, good, and ſettled weather, the mercury is generally high. 3 Upon very great winds, though they be not accompanied with rain, the mercury ſinks loweſt of all, with relation to the point of the compaſs the wind blows upon. 4. The greateſt heights of the mercury are found upon eaſterly or north-eaſterly winds. 5. In calm froſty weather the mercury generally ſtands high. 6. After very great ſtorms of wind, when the mercury has been very low, it generally riſes again very faſt. 7. The more northerly places have greater alterations of the barometer than the more ſoutherly. 8. Within the tropics, and near them, thoſe accounts we have had from others, and the obſervations made at St. Helena, make very little or no variation of the height of the mercury in all weathers.

Hence, I conceive, that the principal cauſe of the riſe and fall of the mercury is from the variable winds which

are

are found in the temperate zone, and whoſe great inconſtancy, here in England, is notorious.

A ſecond cauſe is, the uncertain exhalation and precipitation of the vapours lodging in the air, whereby it comes to be at one time much more crowded than at another, and conſequently heavier; but this latter depends in a great meaſure upon the former. Now, from theſe principles, I ſhall endeavour to explicate the ſeveral phenomena of the barometer, taking them in the ſame order I have laid them down. Thus,

1. The mercury's being low inclines it to rain, becauſe the air being light, the vapours are no longer ſupported thereby, being become ſpecifically heavier than the medium wherein they floated; ſo that they deſcend towards the earth, and, in their fall, meeting with other aqueous particles, they incorporate together, and form little drops of rain: but the mercury's being at one time lower than another, is the effect of two contrary winds blowing from the place where the barometer ſtands; whereby the air of that place is carried both ways from it, and conſequently the incumbent cylinder of air is diminiſhed, and accordingly the mercury ſinks: as, for inſtance, if in the German ocean it ſhould blow a gale of weſterly wind, and, at the ſame time, an eaſterly wind in the Iriſh ſea; or if in France it ſhould blow a northerly wind, and in Scotland a ſoutherly; it muſt be granted, that *that* part of the atmoſphere impendant over England would thereby be exhauſted and attenuated, and the mercury would ſubſide, and the vapours which before floated in theſe parts of the air of equal gravity with themſelves, would ſink to the earth.

2. The

2. The greater height of the barometer is occaſioned by two contrary winds blowing towards the place of obſervation, whereby the air of other places is brought thither and accumulated; ſo that the incumbent cylinder of air being increaſed both in height and weight, the mercury preſſed thereby muſt needs ſtand high, as long as the winds continue ſo to blow; and then the air being ſpecifically heavier, the vapours are better kept ſuſpended, ſo that they have no inclination to precipitate, and fall down in drops; which is the reaſon of the ſerene good weather which attends the greater heights of the mercury.

3. The mercury ſinks the loweſt of all by the very rapid motion of the air in ſtorms of winds. For the tract or region of the earth's ſurface, wherein the winds rage, not extending all round the globe, that ſtagnant air, which is left behind, as likewiſe that on the ſides, cannot come in ſo faſt as to ſupply the evacuation made by ſo ſwift a current; ſo that the air muſt neceſſarily be attenuated when and where the ſaid winds continue to blow; and that more or leſs according to their violence: add to which, that the horizontal motion of the air being ſo quick, may in all probability take off ſome part of the perpendicular preſſure thereof; and the great agitation of its particles is the reaſon why the vapours are diſſipated, and do not condenſe into drops ſo as to form rain, otherwiſe the natural conſequence of the air's rarefaction.

4. The mercury ſtands higheſt upon the eaſterly and north-eaſterly wind; becauſe in the great Atlantic ocean on this ſide the thirty-fifth degree of north latitude, the winds are almoſt always weſterly or ſouth-weſterly; ſo that whenever here the wind comes up at eaſt and north-

north-eaſt, it is ſure to be checked by a contrary gale as ſoon as it reaches the ocean: wherefore, according to our ſecond remark, the air muſt needs be heaped over this iſland, and conſequently the mercury muſt ſtand high, as often as theſe winds blow. This holds true in this country: but is not a general rule for others, where the winds are under different circumſtances: and I have ſometimes ſeen the mercury here ſo low as twenty-nine inches upon an eaſterly wind; but then it blew exceeding hard; and ſo comes to be accounted for by what was obſerved in the third remark.

5. In calm froſty weather the mercury generally ſtands high; becauſe (as I conceive) it ſeldom freezes, but when the winds come out of the northern and north-eaſtern quarters: or at leaſt unleſs thoſe winds blow at no great diſtance off: For the north parts of Germany, Denmark, Sweden, Norway, and all that tract from whence north-eaſtern winds come, are ſubject to almoſt continual froſt all the winter: and thereby the lower air is very much condenſed, and in that ſtate is brought hitherward by thoſe winds; and, being accumulated by the oppoſition of the weſterly wind blowing in the ocean, the mercury muſt needs be preſt to a more than ordinary height; and as a concurring cauſe, the ſhrinking of the lower parts of the air into leſſer room by cold, muſt needs cauſe a deſcent of the upper parts of the atmoſphere, to reduce the cavity made by this contraction to an equilibrium.

6. After great ſtorms, when the mercury has been very low, it generally riſes again very faſt. I once obſerved it to riſe one inch and a half in leſs than ſix hours, after a long continued ſtorm of ſouth-weſt wind. The reaſon is, becauſe the air being very much rarefied by the great

great evacuations which ſuch continued ſtorms make thereof, the neighbouring air runs in the more ſwiftly to bring it to an equilibrium; as we ſee water runs the faſter for having a greater declivity.

7. The variations are greater in the more northerly places; as at Stockholm greater than at Paris (compared by *M. Paſchall*) becauſe the more northerly parts have uſually greater ſtorms of wind than the more ſoutherly, whereby the mercury ſhould ſink lower in that extreme; and then the northerly winds bringing in the more denſe and ponderous air from the neighbourhood of the pole, and that again being checked by a ſoutherly wind at no great diſtance, and ſo heaped, muſt of neceſſity make the mercury in ſuch caſe ſtand higher in the other extreme.

8. Laſtly, this remark, That there is little or no variation near the equinoctial, does, above all others, confirm the hypotheſis of the variable winds being the cauſe of theſe variations of the height of the mercury; for in the places above-named, there is always an eaſy gale of wind blowing nearly upon the ſame point, viz. E. N. E. at Barbadoes, and E. S. E. at St. Helena; ſo that there being no contrary currents of air to exhauſt or accumulate it, the atmoſphere continues much in the ſame ſtate: however, upon hurricanes, the moſt violent of ſtorms, the mercury has been obſerved very low; but this is but once in two or three years; and it ſoon recovers its ſettled ſtate, about 29½ inches.

To fill the Barometer Tube.

IN order to fill a barometer tube to the greateſt perfection, it is neceſſary to obſerve the following rules: 1. That the tube be at leaſt one fourth of an inch bore; but one third of an inch is better. 2. That the tube ought to be new, and clean within when filled. In order to this, the tube ſhould be hermetically ſealed at both ends, at the glaſs-houſe when made; one end of which may be cut off with a file when you uſe it. 3. The diameter of the ciſtern that holds the mercury, in which the tube is immerſed, ſhould be as large as conveniently may be, that the mercury therein may have nearly at all times the ſame altitude; otherwiſe the index will not be true. 4. The mercury muſt be pure and free from any mixture of tin, lead, or other metal. 5. It ought to be purged from air entirely, as it may be by boiling it, and filling the tube with it, while boiling hot, nearly. 6. The tube muſt be heated hot when filled, to avoid breaking by the boiling mercury. 7. It ſhould be rubbed very hard, to excite the electric virtue, which will expel the particles of air from the ſurface within.

Then take the tube, fig. 7, and nearly fill the ball with mercury; after which, place the thumb of your right hand upon the end A, and the fore-finger of your left upon the end B, holding it downwards, and ſhaking it endways, the mercury will run into the tube until it be quite filled; you may then turn it as in the figure, and the mercury will ſink in the tube to B, which will be 29½ inches from the ſurface of the mercury in the ball at A, if the preſſure of the atmoſphere at that time be at changeable, as at Fig. 6. N. B. If any air bubbles

Fig. 7.

ſhould

ſhould happen to be left in the tube after it is filled, you muſt invert it, and place your thumb and fore-finger as before, and gently knock the end B with your finger underneath it, upon a table, while all the air-bubbles have riſen into the ball, then it is perfect; but this operation is never neceſſary, but when the bore of the tube is too ſmall.

The Diagonal Barometer.

A B C, fig. 8, is a tube ſealed at C, immerſed in mercury at A: this tube is perpendicular from A to B, where the ſcale of variation begins; from thence it is bent into C B. This part B C proceeds to the higheſt limit in the ſcale of variation, viz. I C; and conſequently while the mercury riſes from C to I in the common barometer, it will move in this from B to C; and ſo the ſcale will be by this means enlarged in the proportion of B C to I C. Fig. 8.

However, this form being ſubject to a great degree of friction, on account of the obliquity in the part B C; which inclination makes the quickſilver frequently divide into ſeveral parts, requires the trouble of filling the tubes anew too often.

The Horizontal Rectangular Barometer.

CONSISTS of a tube A C D F, fig. 9, ſealed on the upper end A, and bent to a right-angle at D, whence it has the name of the horizontal rectangular barometer. The mercury ſtands in both legs from E to C. The Fig. 9.

ſcale of variation from D to F, is here made of a larger part, and then it is evident, in moving three inches from A to C, it will move through ſo many times 3 inches in the ſmall leg D F, as the bore of D F is leſs than the bore of A C, whence the motion of the mercury at E muſt be extremely ſenſible. This form is liable to the like exceptions, as remarked in that of fig. 8; and, beſides a great degree of friction, and the frequent breaking off of the mercury in the leg E, the part D F being a very ſmall bore, the free motion of the mercury therein muſt be impeded by the attraction of coheſion.

The Wheel Barometer.

fig. 10. A, fig. 10, repreſents the quickſilver in a glaſs tube, having a large round head or ball, and turned up at bottom B; upon the ſurface of the mercury in the recurved leg, there is then placed a ſhort glaſs tube loaded with mercury, with a ſtring going over a pulley, and is balanced by another weight hanging freely in the air. As the ſurface at A is very large, and that at B very ſmall, the motion of the quickſilver, and conſequently of the ball A, will at bottom be very conſiderable; but as the weight moves up and down, it turns the pulley, and that a hand or index; and by the diviſions of a large graduated circle, the minuteſt variations of the air are plainly ſhewn, if the inſtrument be accurately made, and the friction of the ſeveral parts be inconſiderable.

For refining mercury, &c. fit for the above uſe, ſee th Miſcellaneous Articles.

The

The Air-Gun.

THIS pneumatical inſtrument is an ingenious contrivance, which will drive a bullet with great violence, by means of condenſed air, forced into an iron ball, by a condenſer (repreſented Fig. 11.) At the end a of this inſtrument is a male ſcrew, on which the hollow ball b is ſcrewed, in order to be filled with condenſed air. In the inſide of this ball is a valve, to hinder the air after it is injected from making its eſcape, until it be forced open by a pin, againſt which the hammer of the lock ſtrikes (as at a, Fig. 12.); which then lets out as much air as will drive a ball with conſiderable force to a great diſtance. Fig. 12.

When you condenſe the air in the ball, place your feet on the iron croſs h h, to which the piſton rod d e is fixed; then lift up the barrel c a, by the handles i i, until the piſton at e be brought between o and c; the barrel a c will then be filled with air through the hole o from o to a. Then thruſt down the barrel a c by the handles i i until the piſton e join with the neck of the iron ball at a; the air being thus condenſed between o and a will force open the valve in the ball, and when the handles i i are lifted up again, the valve will cloſe and keep in the air: ſo by rapidly continuing the ſtrokes up and down, the ball will preſently be filled; after which unſcrew the ball off the condenſer, and ſcrew it upon another male ſcrew which is connected with the barrel, and goes through the ſtock of the gun, as repreſented at b, Fig. 12. I have frequently injected 12 dwts. of air into a ball $3\frac{3}{4}$ inches diameter, with which I diſcharged 15 bullets with conſiderable force.

The

There are many contrivances in conſtructing air-guns: ſome have a ſmall barrel contained within a large one; and the ſpace between the two barrels ſerves for the reception of condenſed air. In theſe ſort a valve is fixed at a, Fig. 12, with a condenſer fixed to the barrel at a and continued through the but-end to c, as a c, Fig. 11, where the piſton rod may be always left in; and when uſed, an iron pin, one foot long, may be put through the hole d. Place your feet on the pin, and the whole gun ſerves inſtead of the handles i i, Fig. 11, to condenſe the air in the barrel.

The magazine air-gun differs from the common one, only by having a ſerpentine barrel, which contains 10 or 12 balls; theſe are brought into the ſhooting barrel ſucceſſively, by means of a lever; and they may be diſcharged ſo faſt as to be nearly of the ſame uſe with ſo many different guns.

HYDRAULICS,

AND

HYDROSTATICS.

DEFINITIONS.

1. HYDRAULICS is the ſcience of fluids, particularly of water, with a ſpecial attention to artificial water-works; and to the laws and motion of fluid bodies.

HYDROSTATICS explain the equilibrium of fluids, or the gravitation of fluids at reſt; and upon removing that equilibrium, motion enſues: and here hydraulics commence.

Hydraulics, therefore, ſuppoſes *Hydroſtatics*; which induces me to begin this Treatiſe with Hydroſtatics.

2. A *Syphon* is a bended tube, as repreſented Plate IX. Fig. 5.

3. A *valve* is a ſort of flap or cover, fixed to a pipe or other body, which, by opening one way only, ſuffers the water to paſs, but not to return.

4. A

4. A *Piſton* is a ſmall cylinder faſtened to the end of a rod, and fitted to the bore of a pipe or hollow cylinder; and frequently contains a valve.

5. The *Hydrometer* is an inſtrument conſtructed to find the ſpecific gravities of fluids, as Fig. 2.

6. The *Hydroſtatic balance* is contrived to ſhew the ſpecific gravities of fluids, and of ſolids, by weighing them in fluids.

APHORISMS.

1. WATER is a ſcentleſs, tranſparent, colourleſs fluid, which, with a certain degree of cold, turns to ice.

Note. Though fluidity is commonly regarded as an eſſential property of water, yet many philoſophers, particularly *Boyle* and *Boerhaave*, conſider it as an adventitious circumſtance, produced by a certain degree of heat; and aſſert its natural ſtate to be that of chryſtalline, as when in ice.

2. Water is one of the conſtituent parts of all bodies: this is proved by diſtillation; for the dryeſt woods, earths, bones, and ſtones pulveriſed, conſtantly yield a certain quantity of water.

3. All fluids, except air, are incompreſſible.

4. Though water is leſs tranſparent than air, it is more penetrative, as it will pervade bodies that air will not: this is evident from paſſing through the pores of a bladder.

5. Water

5. Water diſſolves ſome bodies, as ſalts, and conglutinates others, as bricks, ſtones, bones, &c.

6. Water in its natural ſtate contains the three other elements, fire, earth, and air.

We have already ſaid that water owes its fluidity to heat, and it is evident from many experiments with the air-pump, that it contains no ſmall quantity of air; and the ſediment that is found in all water, except that which is diſtilled, always contains a quantity of earth. From the laſt element it is ſuppoſed that plants derive all the nouriſhment they receive by means of water.

7. The water, in ſeveral tubes that communicate with each other, will ſtand at the ſame height in all of them, whether they be ſmall or great, perpendicular or oblique.

8. The ſurface of water contained in a veſſel will always be even, and parallel to the horizon: but in large bodies of water, as the ſea, or great lakes, the ſurface will not be plain, but ſpherical, as making a part of the terraqueous globe.

9. In a veſſel of water the preſſure of the upper parts on the lower, is in proportion to the depth; and is the ſame at the ſame depth, whatever be the diameter of the veſſel.

10. The preſſure of a fluid upward is equal to its preſſure downward, at any given depth.

11. The bottom and ſides of a veſſel are preſſed by the fluid it contains, in proportion to its height, without any regard to the quantity.

12. If fluids of different gravities be contained in the ſame veſſel, the heavieſt will be at bottom, the lighteſt at top, and the reſt in proportion to their ſpecific gravities.

13. A body that is heavier than an equal quantity of a fluid, will ſink in that fluid; if it be lighter, it will ſwim at the top; but if it be of the ſame gravity, it will neither ſink nor ſwim, but remain ſuſpended in any part of that fluid.

14. A ſolid immerſed in a fluid is preſſed by that fluid on all ſides, in proportion to the height of the fluid above the ſolid. Bodies very deeply immerged may be conſidered as equally preſſed on all ſides.

15. Every ſolid immerſed in a fluid, loſes ſo much of its weight, as is equal to the weight of a quantity of that fluid of the ſame dimenſion with the ſolid.

16. The fluid acquires the weight the ſolid loſes.

Of Fluidity.

Sir Iſaac Newton's definition of a fluid is, *That it is a body yielding to any force impreſſed, and which has its parts very eaſily moved one among another.*

It muſt here be remarked, that this definition ſuppoſes the motion ſpoken of, produced by a partial preſſure; for in the caſe of an incompreſſible fluid, it is demonſtrated by Dr. *Keil*, that under a total or an equal preſſure, it would be impoſſible the yielding body ſhould move.

The

The original and conſtituent parts of fluids are by the moderns conceived to be, particles ſmall, ſmooth, hard, and ſpherical; according to which opinion, every particle is of itſelf a ſolid, or a fixed body; and when conſidered ſingly, is no fluid, but becomes ſo only by being joined with other particles of the ſame kind.

'Tis probable that the particles of fluids are exceeding ſmall, becauſe their texture has never yet been diſcovered by the fineſt microſcope. We judge them to be ſmooth, becauſe they are found eaſily to glide one over another; hard and impenetrable, becauſe no fluid we are acquainted with, the air excepted, is capable of compreſſion: we conceive them to be ſpherical, that they may only touch in ſome points of their ſurfaces; and ſo not only may be the more eaſily moved, but alſo form interſtices or vacancies between them, which may be proved.

Were fluids not compounded of primary particles, formed as above, but made up of one homogeneous ſubſtance, without conſiſtence equally denſe, there would be no difference in their ſpecific gravity; and all fluids would be of the ſame weight, bulk for bulk; which is contrary to experience.

That fluids have vacuities, will appear upon mixing ſalt with water, a certain quantity whereof will be diſſolved, and thereby imbibed, without enlarging the dimenſions. A fluid's becoming more buoyant, is a certain proof that its ſpecific gravity is increaſed, and of conſequence, that many of its vacuities are thereby filled; after which it may ſtill receive a certain quantity of other diſſoluble bodies, the particles whereof are adapted to the

vacancies remaining, without adding any thing to its bulk, though the abſolute weight of the whole fluid be thereby increaſed. This might be demonſtrated by weighing a phial of rain water, critically, with a nice balance: pour this water into a cup, and add ſalt to it: refund of the clear liquor what will again fill the phial; an increaſe of weight will be found under the ſame dimenſions, from a repletion, as has been ſaid, of the vacuities of the freſh water with ſaline particles.

And as fluids have vacuities, or are not perfectly denſe, it is alſo probable that they are compounded of ſmall ſpheres of different diameters, whoſe interſtices may be ſucceſſively filled with apt materials for that purpoſe: and the ſmaller theſe interſtices are, the greater will the gravity of the fluid always be.

For inſtance: Suppoſe a barrel be filled with bullets in the moſt compact manner, a great many ſmall ſhot may afterwards be placed in the interſtices of thoſe balls; the vacuities of the ſhot may then be repleniſhed with a certain quantity of ſea ſand; the interſtices of the ſand may again be filled with water; and thus may the weight of the barrel be greatly augmented, without increaſing the general quantity: now this being true with regard to ſolids, is applicable alſo to fluids. For inſtance, river-water will diſſolve a certain quantity of ſalt; after which it will receive a certain quantity of ſugar, and after that a certain quantity of alum, and perhaps other diſſoluble bodies, and not increaſe its firſt dimenſions.

Was all ſpace abſolutely full of matter, this matter muſt either be fluid or fixed. Was it fixed, there could poſſibly be

be no motion therein, as is plain both from reaſon and experience; it muſt therefore be fluid. But a fluid without vacuities will be denſer, and conſequently heavier, than all fluids; and if denſer, all bodies will emerge, and ſwim therein, by hydroſtatical laws; nor could there be ſuch a thing as gravity. But as gravity cannot be denied, all ſpace therefore cannot be filled, even with a fluid.

Borelli has demonſtrated, that the conſtituent parts of fluids are not fluid, but conſiſtent bodies; and that the elements of all bodies are perfectly firm and hard. The incompreſſibility of water, proved by the Florentine experiment, is a ſufficient evidence alſo, that each primary particle or ſpeckle thereof is a perfect and impenetrable ſolid.

This famous experiment was firſt attempted by the great Lord Verulam, who incloſed a quantity of water in lead, and found that it inclined rather to make its way through the pores of the metal, than be reduced to leſs compaſs by any force that could be applied. At Florence this experiment was afterwards made more accurately with a globe of ſilver: this being filled with water and well cloſed, was gently preſſed; upon which a ſmall quantity of water iſſued from the globe in form of dew.

Sir Iſaac Newton and others have attempted it ſince with globes made of gold and other metals, and with equal ſucceſs. Mr. Canton has obſerved in ſome experiments made by him, that the different ſtate of the air makes water to be compreſſed at ſome times more than at others: but though naturally it may be thus affected, we cannot by any artificial method compreſs it; for as ſoon as the cold is over, it will return to its former bulk.

The

The Hydroſtatic Balance.

THOUGH the hydrometer is the moſt convenient inſtrument for meaſuring the ſpecific weights of fluids, yet for a meaſure of the ſpecific gravity of all ſubſtances, we muſt have recourſe to the hydroſtatic balance: which is conſtructed in various forms; but we ſhall content ourſelves here with deſcribing that which appears of all others the moſt accurate.

Plate IX. Fig. 1. V C G (Plate IX. fig. 1,) is the ſtand or pillar of this hydroſtatic balance, which is to be fixed in a table. From the top A, hangs, by two ſilk ſtrings, the horizontal bar B B, from which is ſuſpended by a ring i, the fine beam of a balance b: which is prevented from deſcending too low on either ſide by the gentle ſpringing piece l x y z, fixed on the ſupport M. The harneſs is annulated at o, to ſhow diſtinctly the perpendicular poſition of the examen, by the ſmall pointed index fixed above it.

The ſtrings by which the balance is ſuſpended, paſſing over two pullies, one on each ſide of the piece at A, go down to the bottom on the other ſide, and are hung over the hook at v; which hook, by means of a ſcrew P, is moveable, about one inch and one quarter, backward and forward, and therefore the balance may be raiſed or depreſſed ſo much. But if a greater elevation or depreſſion be required, the ſliding-piece S, which carries the ſcrew P, is readily moved to any part of the ſquare braſs rod V K, and fixed by means of a ſcrew.

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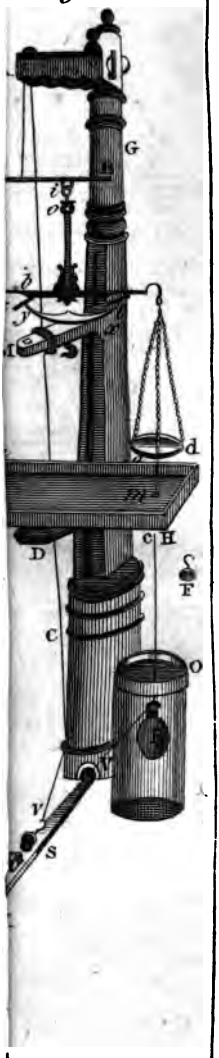

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The motion of the balance being thus adjuſted, the reſt of the apparatus is as follow: H H is a ſmall board, fixed upon the piece D, under the ſcales d and e, and is moveable up and down in a long ſlit in the pillar above C, and faſtened at any part by a ſcrew behind. From the point in the middle of the bottom of each ſcale hangs, by a fine hook, a braſs wire a d and a c; theſe paſs through two holes m m, in the table. To the wire a d is ſuſpended a curious cylindric wire r s, perforated at each end for that purpoſe: this wire r s is covered with paper, graduated by equal diviſions, and is about five inches long.

In the corner of the board at E, is fixed a braſs tube, on which a round wire h l is ſo adapted as to move neither too tight nor too free, by its flat head I. Upon the lower part of this moves another tube Q, which has ſufficient friction to make it remain in any poſition required; to this is fixed an index T, moving horizontally when the wire h l is turned about, and therefore may be eaſily ſet to the graduated wire r s. To the lower end of the wire r s hangs a weight L, and to that a wire p n, with a ſmall braſs ball g, about a quarter of an inch diameter. On the other ſide, to the wire a c, hangs a large glaſs bubble R, by a horſe-hair.

Let us firſt ſuppoſe the weight L taken away, and the wire p n ſuſpended by S; and on the other ſide, let the bubble R be taken away, and the weight F ſuſpended at c, in its room. This weight F we ſuppoſe to be ſufficient to keep the ſeveral parts hanging to the other ſcale in equilibrium; at the ſame time that the middle point of the wire p n is at the ſurface of the water in the veſſel N. The wire p n is to be of ſuch a ſize, that the length of one inch ſhall weigh four grains.

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Plate IX. Fig. 1.

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PLATE IX.

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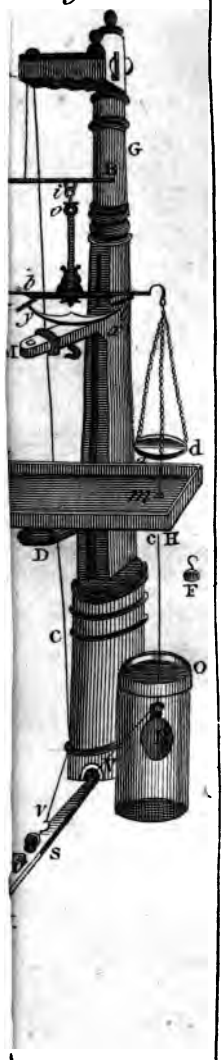

J. Lodge sc.

The motion of the balance being thus adjuſted, the reſt of the apparatus is as follow: H H is a ſmall board, fixed upon the piece D, under the ſcales d and e, and is moveable up and down in a long ſlit in the pillar above C, and faſtened at any part by a ſcrew behind. From the point in the middle of the bottom of each ſcale hangs, by a fine hook, a braſs wire a d and a c; theſe paſs through two holes m m, in the table. To the wire a d is ſuſpended a curious cylindric wire r s, perforated at each end for that purpoſe: this wire r s is covered with paper, graduated by equal diviſions, and is about five inches long.

In the corner of the board at E, is fixed a braſs tube, on which a round wire h l is ſo adapted as to move neither too tight nor too free, by its flat head I. Upon the lower part of this moves another tube Q, which has ſufficient friction to make it remain in any poſition required; to this is fixed an index T, moving horizontally when the wire h l is turned about, and therefore may be eaſily ſet to the graduated wire r s. To the lower end of the wire r s hangs a weight L, and to that a wire p n, with a ſmall braſs ball g, about a quarter of an inch diameter. On the other ſide, to the wire a c, hangs a large glaſs bubble R, by a horſe-hair.

Let us firſt ſuppoſe the weight L taken away, and the wire p n ſuſpended by S; and on the other ſide, let the bubble R be taken away, and the weight F ſuſpended at c, in its room. This weight F we ſuppoſe to be ſufficient to keep the ſeveral parts hanging to the other ſcale in equilibrium; at the ſame time that the middle point of the wire p n is at the ſurface of the water in the veſſel N. The wire p n is to be of ſuch a ſize, that the length of one inch ſhall weigh four grains.

Now

Now it is evident, ſince braſs is eight times heavier than water, that for every inch the wire ſinks in the water it will become half a grain lighter, and half a grain heavier for every inch it riſes out of the water: conſequently by ſinking two inches below the middle point, or riſing two inches above it, the wire will become one grain lighter or heavier. Therefore, if when the middle point is at the ſurface of the water in equilibrium, the index T be ſet to the middle point a of the graduated wire r s, and the diſtance on each ſide a r and a s contains a hundred equal parts; then, if in weighing bodies the weight is required to the hundredth part of a grain, it may be eaſily had by proceeding in the following manner:

Let the body to be weighed be placed in the ſcale d. Put the weight X in the ſcale e, and let this be ſo determined that one grain more ſhall be too much, and one grain leſs too little. Then the balance being moved gently up or down, by the ſcrew P, till the equilibrium be nicely ſhewn at o; if the index T be at the middle point a of the wire r s, it ſhews that the weights put into the ſcale e, are juſt equal to the weight of the body. By this method we find the abſolute weight of the body; the relative weight is found by weighing it hydroſtatically in water, as follows:

Inſtead of putting the body into the ſcale e, as before, let it hang with the weight F, at the hook c, by a horſe-hair, as at R, ſuppoſing the veſſel O of water were away. The equilibrium being then made, the index T ſtanding between a and r, at the thirty-ſixth diviſion, ſhews the weight of the body put in to be 1095,36 grains. As it thus hangs let it be immerſed in the water of the veſſel O, and it will become much lighter: the ſcale e will deſcend till

till the beam of the balance reſt on the ſupport x. Then ſuppoſe 100 grains put in the ſcale d, reſtore the equilibrium preciſely, ſo that the index T ſtand at the thirty-ſixth diviſion above a; it is evident that the weight of an equal bulk of water would, in this caſe, be exactly 100 grains.

After a like manner this balance may be applied to find the ſpecific gravities of fluids; as is eaſy to conceive from what has been ſaid.

The Hydrometer.

THIS is the moſt eligible of all inſtruments for finding the ſpecific gravity of fluids only, as well for eaſe as expedition.

The globe of the hydrometer ſhould be made of copper, for ivory imbibes ſpirituous liquors, and thereby alters their gravity; and glaſs requires an attention that is incompatible with expedition. The moſt ſimple hydrometer conſiſts of a copper ball B b, to which is ſoldered a braſs wire A B, one quarter of an inch thick. The upper part of this wire being filed flat, is marked *proof*, at m, fig. 3, becauſe it ſinks exactly to that mark in proof ſpirits. There are two other marks at A and B, fig. 2, to ſhew whether the liquor be one-tenth above, or below proof, according as the hydrometer ſinks to A, or emerges to B, when a braſs weight, as C or K, is ſcrewed to its bottom c. There are other weights to ſcrew on, which ſhew the ſpecific gravity of different fluids, quite down to common water. Plate IX. Fig. 2 and 3.

The round part of the wire above the ball, may be marked ſo as to repreſent river water when it ſinks to R W, fig. 3, the weight which anſwers to that water being then ſcrewed on; and when put into ſpring water, mineral water, ſea water, and water of ſalt ſprings, it will gradually riſe to the marks S P, M I, S E, S A; on the contrary, when it is put into Briſtol water, rain water, port wine, and mountain wine, it will ſucceſſively ſink to the marks b r, r a, p o, m o. Inſtruments of this kind are ſometimes called areometers.

There is another ſort of hydrometer that is calculated to aſcertain the ſpecific gravity of fluids to the greateſt preciſion poſſible, and which conſiſts of a large hollow ball B, fig. 4, with a ſmaller bolt b ſcrewed on to its bottom, partly filled with mercury, or ſmall ſhot, in order to render it but little ſpecifically lighter than water. The larger ball has alſo a ſhort neck at C, into which is ſcrewed the graduated braſs wire A C, which, by a ſmall weight at A, cauſes the body of the inſtrument to deſcend in the fluid with part of the ſtem.

Fig. 4.

When this inſtrument is ſwimming in the liquor contained in the jar I L M K, the part of the fluid diſplaced by it, will be equal in bulk to the part of the inſtrument under water, and equal in weight to the whole inſtrument. Now, ſuppoſe the weight of the whole to be 4000 grains, it is evident we can by this means compare the different dimenſions of 4000 grains of ſeveral ſorts of fluids. For if the weight at A be ſuch as will cauſe the ball to ſink in rain water, till its ſurface comes to the middle point of the ſtem 20; and after that, if it be immerſed in common ſpring water, and the ſurface be obſerved to ſtand

at

at one-tenth of an inch below the middle point 20, it is apparent that the ſame weight of each water differs only in bulk, by the magnitude of one-tenth of an inch in the ſtem.

Now, ſuppoſe the ſtem to be ten inches long and weigh 100 grains, then every tenth of an inch will weigh one grain; and as the ſtem is of braſs, which is about eight times heavier than water, the ſame bulk of water will be equal to one-eighth of a grain, and conſequently to the one-eighth of one-fourth thouſandth part; that is, one-thirty-ſecond thouſandth part of the whole bulk. This inſtrument is capable of ſtill greater preciſion, by making the ſtem or neck conſiſt of a flat thin ſlip of braſs, inſtead of one that is cylindrical; for by this means we increaſe the ſurface, which is the moſt requiſite circumſtance, and diminiſh the ſolidity, which neceſſarily renders the inſtrument ſtill more accurate.

To adapt this inſtrument to all purpoſes, there ſhould be two ſtems to ſcrew on and off, in a ſmall hole at a. One ſtem ſhould be a ſmooth thin ſlip of braſs, or rather ſteel, like a watch-ſpring ſet ſtraight, ſimilar to that we have juſt mentioned, on one ſide of which is to be the ſeveral marks or diviſions to which it will ſink in different ſorts of water; as rain, river, ſpring, ſea, and ſalt ſpring waters, &c. and on the other ſide you may mark the diviſions to which it ſinks in various lighter fluids; as hot Bath water, Briſtol water, Lincomb water, Cheltenham water, Port wine, Mountain, Madeira, and other ſorts of wines. But here the weight at A, on the top, muſt be a little leſs than before, when it was uſed for heavier waters.

But in trying the ſtrength of the ſpirituous liquors, a common cylindric ſtem will do beſt, becauſe of its ſtrength and ſteadineſs: and this ought to be ſo contrived, that when immerſed in what is called proof ſpirit, the ſurface of the ſpirit may be upon the middle point 20; which is eaſily done by duly adjuſting the ſmall weight A, on the top, and making the ſtem of ſuch a length, that when immerſed in water, it may juſt cover the ball and riſe to a; but when immerſed in pure ſpirit, it may riſe to the top A. Then by dividing the upper and lower parts A 20, and a 20, into ten equal parts each, when the inſtrument is immerſed in any ſort of ſpirituous liquor, it will immediately ſhew how much it is above or below proof.

Proof ſpirit conſiſts of half water and half pure ſpirit; that is, ſuch as when poured on gunpowder and ſet on fire, will burn all away; and permits the powder to take fire and flaſh, as in open air. But if the ſpirit be not ſo highly rectified, there will remain ſome water, which will make the powder wet, and unfit to take fire. Proof ſpirit of any kind, weighs ſeven pounds twelve ounces per gallon.

The common method of ſhaking the ſpirits in a phial, and raiſing a head of bubbles, to judge by their manner of riſing or breaking, whether the ſpirit be proof or near it, is very fallacious. There is no way ſo certain, and at the ſame time ſo eaſy and expeditious, as this by the hydrometer: which will infallibly demonſtrate the difference of bulks, and conſequently the ſpecific gravities in equal weights of ſpirits, to the thirty, forty, or fifty thouſandth part of the whole; which is a degree of accuracy no one can wiſh to exceed.

My

My friend Mr. Dicas, of Liverpool, has obtained his Majeſty's letters patent for the compleateſt hydrometer I have yet ſeen.

On the Syphon.

IF a ſmall ſyphon, whoſe legs are of equal length, be filled with water, and turned downward, the fluid will not run off, but remain ſuſpended therein, ſo long as it is held exactly level: but when an inclination to either leg is given, whereby one in effect is made ſhorter than the other, the water will ſhoot out by the longer leg.

The air is a fluid, whoſe denſity near the ſurface of the earth is experimentally found to be to that of water, at a medium, as 1 to 850; ſo that 850 gallons of air, near the earth, weigh as much as one gallon of water. Now, according to the nature of all other fluid bodies, the air preſſes the ſurface of all things expoſed to it every way equally. When therefore the legs of the ſyphon, equal in length, are turned down, the weight of the atmoſphere above being kept off by the machine, the under air, bearing againſt and repreſſing the water, endeavouring to fall out of either of them, with equal force, keeps it in ſuſpenſe, and prevents its motion. But when, by inclining it to either ſide, we in effect ſhorten one of its legs, and prolong the other, an advantage is given to the weightier fluid to preponderate or overweigh; the water then begins to deſcend, and by its continuity brings away the whole.

And to obſerve how ſmall an inclination will ſerve this purpoſe, one need only take a couple of jars full of water, and

and hang a ſmall ſyphon, whoſe legs are of equal length, upon the edge of one; the external leg whereof will, from the ſloping of the jar, naturally incline a little, and the ſyphon will ſoon begin to act, by the attraction of coheſion before mentioned; then taking it on the edge of the other jar, the like will immediately happen: and thus reciprocally may the effect be produced as often and as ſuddenly as you pleaſe.

And hence the reaſon why in practice the legs of the ſyphon are uſually made of unequal lengths; and why the ſhorter leg is put into the liquor, and the fluid decanted by the other, will in part appear.

Fig. 5. It is evident from what has been ſaid, that the two legs of the ſyphon being of equal length in the plane A B, are there equally repreſſed by the atmoſphere; and was the crane filled with liquor only to that height, and held level, no motion of the fluid would follow, till an advantage by inclining it ſhould be given, as before ſaid. Inſtead of which inclination a length of pipe, of ſome inches perhaps, as from B to C in the figure, is commonly added to theſe machines, which, previous to the operation, is ordinarily filled as well as the reſt with a groſs fluid, many degrees heavier than a like quantity of air, wherewith it is then compared; by the gravity whereof the oppoſite ſide becomes greatly overbalanced: and therefore liquors are by this machine uſually decanted with a good deal of rapidity.

Of the Syphon diſguiſed.

A Syphon may be diſguiſed in a cup, from which no liquor will flow till the fluid is raiſed therein to a certain height; but when the efflux is once begun, it will continue till the veſſel is emptied. For inſtance: Fig. 6. is a cup, in the centre whereof is fixed a glaſs pipe A, continued through the bottom at B, over which is put another glaſs tube, made air-tight at top by means of the cork at C, but left ſo open at foot, by holes made at D, that the water may freely riſe between the tubes as the cup is filled. Till the fluid in the cup ſhall have gained the top of the inmoſt pipe at A, no motion will appear: the air, however, from between the two pipes, being in the mean time extruded, by the riſe of the denſer fluid, and paſſing down the inner tube, will get away at bottom, and the water, as ſoon as the top of the incloſed tube ſhall be covered thereby, will very ſoon follow, and continue to riſe in this machine, as in the ſyphon, till the whole is run off. Fig. 6.

This is called by ſome a *Tantalus* cup; and to humour the thought, a hollow figure is ſometimes put over the inner tube, of ſuch length, that when the fluid is got nearly up to the lips of the man, the ſyphon may begin to act, and empty the cup.

This is in effect no other than if the two legs of the ſyphon were both either in the veſſel, as in Fig. 7, into which the water poured will riſe in the ſhorter leg of the machine, by its natural preſſure upwards, to its own level; and when it ſhall have gained the bend of the ſyphon, it will come away by the longer leg, as already deſcribed. Fig. 7.

The

The Hydroſtatical Paradox.

THE hydroſtatical paradox, as by ſome it is called, depends on the equal preſſure of the parts of fluids every-where at the ſame depth. It is this: Any quantity of fluid, however ſmall, may be made to counterpoiſe and ſuſtain any weight, how large ſoever.

Fig. 8. Let A B D G repreſent a cylindrical veſſel, to the inſide of which is fitted the cover C, which, by means of leather at the edge, will eaſily ſlide up and down in the internal cavity, without permitting any water to paſs between its edges and the ſurface of the cylinder. In the cover is inſerted the ſmall tube C F, which is open at top, and communicates with the inſide of the cylinder beneath the cover at C. The cylinder is filled with water and the cover put on. Then, if the cover be loaded with the weight, ſuppoſe of a pound, it will be depreſſed, the water will riſe in the tube to E, and the weight will be ſuſtained. If another pound be added, the water will riſe to F, and the weight will be ſuſtained, and ſo forth, according to the weight added, and the length of the tube. Now the weight of the water in the tube is but a few grains, yet its lateral preſſure ſerves to ſuſtain as much as the weight of a column of water, whoſe baſe is equal to that of the cylinder, and height equal to that in the tube. Thus, the column E C produces a preſſure in the water contained in the cylinder, equal to what would have been produced by the column A a d D; and as this preſſure is exerted every way equally, the cover will be preſſed upwards with a force equal to the weight of A a d D; conſequently if A a d D would weigh a pound, E C will ſuſtain a pound. And the like of other heights

The motion of the balance being thus adjuſted, the reſt of the apparatus is as follow: H H is a ſmall board, fixed upon the piece D, under the ſcales d and e, and is moveable up and down in a long ſlit in the pillar above C, and faſtened at any part by a ſcrew behind. From the point in the middle of the bottom of each ſcale hangs, by a fine hook, a braſs wire a d and a c; theſe paſs through two holes m m, in the table. To the wire a d is ſuſpended a curious cylindric wire r s, perforated at each end for that purpoſe: this wire r s is covered with paper, graduated by equal diviſions, and is about five inches long.

In the corner of the board at E, is fixed a braſs tube, on which a round wire h l is ſo adapted as to move neither too tight nor too free, by its flat head I. Upon the lower part of this moves another tube Q, which has ſufficient friction to make it remain in any poſition required; to this is fixed an index T, moving horizontally when the wire h l is turned about, and therefore may be eaſily ſet to the graduated wire r s. To the lower end of the wire r s hangs a weight L, and to that a wire p n, with a ſmall braſs ball g, about a quarter of an inch diameter. On the other ſide, to the wire a c, hangs a large glaſs bubble R, by a horſe-hair.

Let us firſt ſuppoſe the weight L taken away, and the wire p n ſuſpended by S; and on the other ſide, let the bubble R be taken away, and the weight F ſuſpended at c, in its room. This weight F we ſuppoſe to be ſufficient to keep the ſeveral parts hanging to the other ſcale in equilibrium; at the ſame time that the middle point of the wire p n is at the ſurface of the water in the veſſel N. The wire p n is to be of ſuch a ſize, that the length of one inch ſhall weigh four grains.

Now

PLATE IX.

Fig. 1.

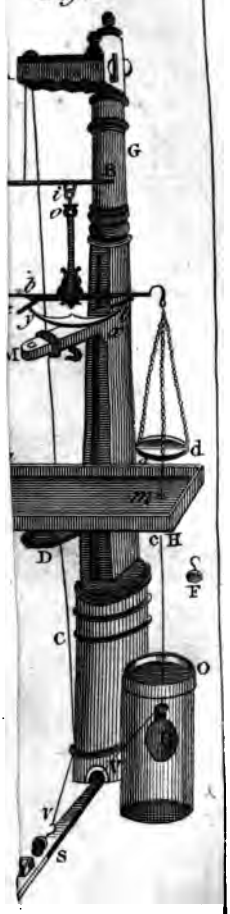

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Plate IX. Fig. 1.

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Upon this principle of the upward preſſure of fluids, a piece of lead may be made to ſwim in water, by immerſing it to a proper depth, and keeping the water from getting above it. Let C D be a glaſs tube open throughout, and E F G a flat piece of lead, exactly fitted to the lower end of the tube, not to go within it, but for it to ſtand upon, with a wet leather between the lead and the tube to make cloſe work. Let this leaden bottom be half an inch thick, and held cloſe to the tube, by pulling the packthread I H L upward at L with one hand, whilſt the tube is held in the other by the upper end C. In this ſituation, let the tube be immerſed in water in the glaſs veſſel A B, to the depth of ſix inches below the ſurface of the water at K: and then the leaden bottom E F G will be plunged to the depth of ſomewhat more than eleven times its own thickneſs: holding the tube at that depth, you may let go the thread at L, and the lead will not fall from the tube, but will be kept to it by the upward preſſure of the water below it, occaſioned by the height of the water at K above the level of the lead: for as lead is 1,133 times as heavy as its bulk of water, and is in this experiment immerſed to a depth ſomewhat more than 1,133 times its thickneſs, and no water getting into the tube between it and the lead, the column of water E a b c G below the lead, is preſſed upward againſt by the water K D E G L all around the tube; which water being a little more than 1,133 times as high as the lead is thick, is ſufficient to balance and ſupport the lead at the depth K E. If a little water be poured into the tube upon the lead, it will increaſe the weight upon the column of water under the lead, and cauſe the lead to fall from the tube to the bottom of the glaſs veſſel, where it will lie in the ſituation b d. Or if the tube be raiſed a little in the water, the lead will fall by its own weight, which will then be too

How lead may be made to ſwim in water.

Fig. 11.

great for the preſſure of the water round the tube, upon the column of water below it.

How light wood may be made to lie at the bottom of water. Fig. 11.

Let two pieces of wood be planed quite flat, ſo as no water may get between them when they are put together: let one of the pieces, as b d, be cemented to the bottom of the veſſel A B, and the other piece be laid flat and cloſe upon it, and held down to it by a ſtick, whilſt water is poured into a veſſel; then remove the ſtick, and the upper piece of wood will not riſe from the lower one; for as the upper one is preſſed down, both by its own weight and the weight of all the water over it, whilſt the contrary preſſure of the water is kept off by the wood under it, it will lie as ſtill as a ſtone would do in its place. But if it be raiſed ever ſo little at any edge, ſome water will then get under it, which being acted upon by the water above, will immediately preſs it upward; and as it is lighter than its bulk of water, it will riſe and float upon the ſurface of the water.

All fluids weigh juſt as much in their own elements as they do in open air. To prove this by experiment, let as much ſhot be put into a phial as, when corked, will make it ſink in water: and being thus charged, let it be weighed firſt in the air, and then in water, and the weights in both caſes wrote down. Then as the phial hangs ſuſpended in water, and counterpoiſed, pull out the cork, that water may run into it, and it will deſcend and pull out that end of the beam. This done, put as much weight into the oppoſite ſcale as will reſtore the equipoiſe; which weight will be found to anſwer exactly to the additional weight of the phial when it is again weighed in air with the water in it.

The velocity with which water ſpouts out at a hole in the ſide or bottom of a veſſel, is as the ſquare root of the

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Now

any part of the diameter to the circumference of the ſemicircle. Thus, if the veſſel A B be full of water, the horizontal pipe D be in the middle of its ſide, and the ſemicircle N d c b be deſcribed upon D as ac enter, with the radius or ſemi-diameter D g N or D f b, the perpendicular D d to the diameter N D b is the longeſt that can be drawn from any part of the diameter to the circumference N d c b. And if the veſſel be kept full, the jet G will ſpout from the pipe D to the horizontal diſtance N M, double the length of the perpendicular D d. If two other pipes, as C and E, be fixed into the ſide of the veſſel at equal diſtances above and below the pipe D, the perpendicular, C c and E c, from theſe pipes to the ſemicircle will be equal: and the jets F and H ſpouting from them, will each go to the horizontal diſtance N K; which is double the length of either of the equal perpendiculars C c or E H.

Of Suction by Machines.

THE quantity of the air's preſſure may be demonſtrated either by experience on the pump itſelf, or by its equipoiſing, and at a medium ſuſtaining 29 and a half inches of mercury, a fluid near fourteen times heavier than water, in the barometer. And that whereby we know that the air's preſſure on the ſurface of the fluid cauſes the water to riſe in the pump, and become certain that it proceeds from no property, power, or efficacy in ſuction, is, that in the air, water, and even a fluid ſo denſe as mercury, may be raiſed by proper machines; but if the air's preſſure be removed, it cannot be raiſed at all; as may be ſhewn by an exhauſting ſyringe, commonly termed a ſucking ſyringe, to diſtinguiſh it from a forcing

The motion of the balance being thus adjuſted, the reſt of the apparatus is as follow: H H is a ſmall board, fixed upon the piece D, under the ſcales d and e, and is moveable up and down in a long ſlit in the pillar above C, and faſtened at any part by a ſcrew behind. From the point in the middle of the bottom of each ſcale hangs, by a fine hook, a braſs wire a d and a c; theſe paſs through two holes m m, in the table. To the wire a d is ſuſpended a curious cylindric wire r s, perforated at each end for that purpoſe: this wire r s is covered with paper, graduated by equal diviſions, and is about five inches long.

In the corner of the board at E, is fixed a braſs tube, on which a round wire h l is ſo adapted as to move neither too tight nor too free, by its flat head I. Upon the lower part of this moves another tube Q, which has ſufficient friction to make it remain in any poſition required; to this is fixed an index T, moving horizontally when the wire h l is turned about, and therefore may be eaſily ſet to the graduated wire r s. To the lower end of the wire r s hangs a weight L, and to that a wire p n, with a ſmall braſs ball g, about a quarter of an inch diameter. On the other ſide, to the wire a c, hangs a large glaſs bubble R, by a horſe-hair.

Let us firſt ſuppoſe the weight L taken away, and the wire p n ſuſpended by S; and on the other ſide, let the bubble R be taken away, and the weight F ſuſpended at c, in its room. This weight F we ſuppoſe to be ſufficient to keep the ſeveral parts hanging to the other ſcale in equilibrium; at the ſame time that the middle point of the wire p n is at the ſurface of the water in the veſſel N. The wire p n is to be of ſuch a ſize, that the length of one inch ſhall weigh four grains.

Now

of the water in the well, a preſſure not to be excluded from the bowels of a body ſo porous as the earth, being thus ſettled, the parts of this machine, with the manner in which they act, will next come under conſideration.

On the Pump.

THIS uſeful piece of mechaniſm was firſt invented by *Cteſebes*, a mathematician of Alexandria, about 120 years before Chriſt. When the air's preſſure came afterwards to be known, it was much improved, and is now brought to a great degree of perfection.

Of this machine there are ſimply three kinds, viz. the ſucking, the forcing, and the lifting pump. By the two laſt, water may be raiſed to any height with an adequate apparatus and ſufficient power: by the former, it may by the general preſſure of the atmoſphere on the ſurface of the well-water, be raiſed no more than 33 feet, as was before hinted, though in practice it is ſeldom applied to the raiſing it much above 28; becauſe from the variations obſerved on the barometer, it is apprehended that the air may on certain occaſions be ſomething lighter than 33 feet of water; and whenever that ſhall happen, for want of the counterpoiſe, this pump may fail in its performance.

On the Sucking-Pump.

Plate X. Fig. 1. THE common and moſt uſual pump, conſiſts of a pipe open at both ends, in which there is a ſliding piſton as large as the bore, which by means of the hand, or ſome other contrivance, may be moved up and down without ſuffering any air to come between it and the ſides of the pipes; which is alſo called the barrel.

If

Fig. 2.

Fig. 1.

Fig. 2.

Fig. 1.

Plate X.
Fig. 1.

If the lower end of this pipe and piſton be put into water, and the piſton, by lifting away the column of upper air, a vacuum will be made in the pipe, upon which the atmoſphere preſſing upon the well-water, will force it to follow the piſton even to the height of 33 feet, if the ſtroke could be of that continued length; and if there be a valve or clack, ſomething like a trap-door, to ſhut downward, as Fig. 2, placed in ſome convenient part of the pipe, below the water ſo raiſed, as at C, Fig. 1, it will be retained therein; but if this contrivance is wanting, upon letting down the piſton again, the water will recede along with it towards the ſpring; ſo that by the motion of the piſton up and down, the water indeed might riſe and ſink in the barrel at every ſtroke; but without an under valve to confine and keep it there, none can be drawn for ſervice in the common way. Fig. 2. Fig. 1.

The frame A of theſe valves is uſually made of wood, exactly fitted to the bore of the pipe, and not over thick, that it may not ſtop too much of the water-way; to this the hinge of the leather flap B, which is uſually lined with lead, not only to make it fall readily, but to give it ſtrength ſufficient to bear the weight of the water raiſed without warping, is commonly nailed. Fig. 2.

In this kind of pump there is beſides this fixed valve, a moveable one for conveniency, placed in the piſton as at D, alſo opening upwards, or the way the water is to riſe. Such a piſton is commonly called the bucket. Fig. 1.

When the bucket of this machine deſcends, if the bore of the pipe be already full of water, the reſiſtance

thereof will puſh open the moving valve, and part of the water will get above, and when the piſton is drawn upwards, this valve will cloſe under the incumbent weight, and the water will be raiſed by the force applied; ſo that whenever the moveable valve, by being raiſed, is made to lift the weight of the column, as well of air as of water lying thereon, the fixed valve is diſcharged of all preſſure; and then a quantity of water, preciſely equal to that lifted and drawn off by the bucket, will by the ordinary preſſure of the atmoſphere (as was ſaid) on the water in the well, be forced or rather weighed up through it to repleniſh the pipe or barrel. This alternate action of the two valves is viſible through the glaſs pumps, and is worthy of remark.

But if the bore of this machine be full of air only, before water can be drawn, that air muſt be exhauſted, which may be done if the piſton-valve be tight, by the ordinary motion thereof; but for the greater certainty and expedition, water is commonly poured thereon down the pipe, vulgarly called fetching the water; which is of no other uſe than to wet the valves, and to ſupple the collar of leathers fixed to the piſton, and ſpread it that it may lie cloſe to the ſides of the barrel, and ſuffer neither the upper air nor water to eſcape by it, when it is moved up and down.

The firſt ſtroke of the pump, if ſufficiently long, will make a vacuum in the pipe; if otherwiſe, an approach is only made towards it, and but a part of the contained air lifted away; upon which the air remaining in the cavity of the bore, from its natural ſpring, will be conſiderably dilated: to reſtore the natural denſity whereof, the atmoſphere then preſſing harder on the well water than the dilated air does on that in the pipe, will cauſe

the

the water to riſe therein ſo far, as that, together with the included air (yet a little rarefied by the depending weight of water) it ſhall juſt counterpoiſe the weight of the outward air. The very ſame thing will happen again on a repetition of the ſtroke, till by degrees the water ſhall have reached the moving valve, and then the proceſs will go on ſteadily as before deſcribed. And water, by means of this contrivance, may be raiſed to any height whatever, if the power applied be ſufficient to lift the weight, and the pipes ſtrong enough to bear the fluid's natural preſſure.

The preſſure on the pipes in pump-work is in proportion to the ſtanding height of the fluid above the part conſidered: but the weight incumbent on the bucket (or moving valve) of a pump in action, is near'y proportionable to that of a column of water raiſed: for tho' the puſh of the atmoſphere on the ſurface of the ſpring, when the bucket riſes, be really equal to the weight of 33 feet of water; yet is this reſiſtance counterbalanced exactly by the weight of the atmoſphere, ever incumbent on the ſurface of the water thereby raiſed: ſo that all the advantage to be obtained by, or expected from hydraulic machines, or engines to raiſe water, as well indeed as from all other pieces of mechaniſm whatever, is only the putting matters into a convenient method of being executed, and the performance depends on the moving power entirely, under the diſadvantage of friction always againſt it.

Of the Diſpoſition of Pump-Work.

A Pump intended to raiſe water to any height whatever, will always work as eaſy, and require no greater

power to give motion to the bucket, if both the valves be placed towards the bottom of the pipe, than if they were fixed 33 feet above the ſurface of the water.

The playing of the piſton thus low in the pipe, will beſides prevent an inconvenience which might happen, were it placed above, viz. in caſe of a leak beneath the bucket, which, in a great length of pipe, may very eaſily happen, the outward air getting through, would hinder the neceſſary rarefaction of the air in the barrel, on moving the piſton; and conſequently the pump might fail in its operation. This can only effectually be prevented by placing the pump-work in or near the water. In which caſe, ſhould any leak happen upward, it will only occaſion the loſs of ſome of the water, without any other inconvenience. And the leather valves being thus kept under water, will always be found ſupple, pliant, and in a fit condition to perform their office.

It may indeed be here objected, that the ſpecific weight of the iron rod, to which the bucket is fixed, will be an incumbrance to the working of the pump; but if it be made of oak, when well ſoaked, it will be nearly of the ſame ſpecific weight with water, and ſo no burden on the moving power when the ſtroke is fetched.

Placing the pump-work (that is, the valve and piſton) pretty low and near together, will alſo prevent the inconvenience of our not being able in all caſes to fetch up water from the ſpring, by the ordinary pump, when of an equal bore, by reaſon of the ſhortneſs of the ſtroke; which therefore cannot rarefy the air ſufficiently to bring

bring the water up to the piſton from the lower valve. For inſtance: take a ſmooth barrelled pump, 21 feet long, having its piſton fetching ſuppoſe a foot ſtroke, placed above, and the clack or fixed valve at the other end below. By the playing of the piſton, admit it poſſible for water to riſe 11 feet; or if you will, let water be poured on the clack, to the height of 11 feet, and refit the piſton, there will remain ſtill 9 feet of air between it and the water, which cannot be ſufficiently rarefied by a foot-ſtroke to open the clack, or fetch up more water: for in this caſe the air can only be rarefied in the proportion of 9 to 10; whereas to make a bare equilibrium with the atmoſphere, it ought to be as 9 to 13 and a half: ſince, as 22 or the complement of 11, to 33 feet of water, the weight of the whole atmoſphere is to 33 feet or the atmoſphere, ſo is the interval ſpoken of, 9 to 13 and a half; to complete which, the ſtroke ought to be at leaſt 4 feet and a half long.

However, by filling the whole void between the piſton and clack at firſt with water, this laſt objection might be removed.

Of the Diſpoſition of Pipes of Conduit.

IN ſome caſes the pump cannot be placed conveniently perpendicular to the well; for example, being to raiſe water out of the well at A by means of a pump at B, the beſt way will be to carry the barrel as low as the ſpring is, communicating therewith by means of the pipe at C. The bucket then playing in the barrel B C, will have the ſame effect as if the well was made perpendicular Fig. 3.

pendicular to the pump; becauſe the water by its proper weight, will always repleniſh B C, through A, through the level of the well-water at F.

And if it ſhould happen, from ſome conſiderable impediment, that the barrel cannot go down to the well directly, it may be led about any other way for ſake of convenience. And then making the pipe of conveyance E, leſs in diameter than the barrel, it will ſooner be exhauſted of air, by moving the piſton; and the water will follow very briſkly, as by the leaden pump at D.

It will, however, always be more eaſy to draw water with pipes that are large, and of an equal bore throughout, becauſe the water will have a leſs velocity in them, and the friction will be in proportion leſs. Upon this account, the pumps ordinarily made by the plumbers go not ſo eaſy as thoſe bored out of trees; becauſe, by making their pipe that brings up water from the ſpring ſo much leſs than the bucket, they, as it were, wire-draw the water raiſed. If the barrel, for inſtance, be four inches in diameter, and the pipe of conduit one, it will in riſing move ſixteen times as faſt through this as it will in that, to the expence of needleſs labour, as well as the great wear and friction of the machine.

For the like reaſon, it will alſo be a fault to bore a pump conically upward, becauſe the water cannot with freedom get away ſo faſt, as a vacuum may be made in the moving piſton; and the reflection of the water from the ſides, will always be a hindrance to the operation.

In practice, however, it is generally obſerved, that ſuch leaden pumps as work pleaſantly, and are light on

on the hand, have the water-way in the ſucking pipe nearly equal to one-fourth of the area of the barrel; and accordingly an inch and half pipe will pretty well ſupply a three inch barrel; and a four inch barrel ſhould have a leading-pipe nearly two inches in diameter.

Of the Lifting-Pump.

THE ſtructure of the lifting-pump differs from that of the ſucking-pump in nothing but the diſpoſition. As that has its fixed valve below and the moveable one above, in the barrel A B (Fig. 1.) this is juſt the contrary, as C and D. As the bucket or piſton of that is moved by a rod within the bore of the pipe, this is ſo by means of a ſtrong frame fixed to a rod without at E. As in that it is of advantage, for fear of a leak, to have the pump-work, if poſſible, in or near the ſource of water; this in practice is commonly ſo done, and for that reaſon is very ſeldom ſubject to any failure in its performance. An elbow in this kind of pump, to lead the lifted water clear of the playing of the rod, which of neceſſity muſt move perpendicularly, is unavoidable. The friction occaſioned hereby will however always be leſs the nearer this bend comes to a ſtraight line. Fig. 4.

From the name and ſtructure of this machine, it may be imagined, perhaps, that the air's preſſure is not of equal ſervice to this kind of pump as to the former; but it is quite otherwiſe. For if both valves be not perfectly air-tight, water cannot be well raiſed thereby; but in caſe neither of them is defective, water will be raiſed

raiſed to very good purpoſe, by much the ſame kind of proceſs as that of the ſucking pump, before explained. Nor is there any doubt but that if two machines, a ſucking and a lifting-pump, were made of equal bores, wrought with equal force, and were in every circumſtance alike, they would be found of equal ſervice in raiſing water.

On the Forcing-Pump.

Fig 5. THIS pump conſiſts of a barrel A B, a piſton or forcer C, leathered upwards, that it may withſtand the preſſure of the atmoſphere from above, that ſo by ſucking, when raiſed, it may bring up the water to ſupply the barrel; and 'tis alſo leathered downwards, that when repreſſed, it may reſiſt the weight of the water to be forced up, or raiſed for uſe. There are always two fixed valves in this kind of pump; one in ſome convenient part of the ſucking-pipe, as at D, the other in the branching or forcing pipe, as E. Theſe ought in like manner to be air-tight, and ſo diſpoſed as to let the water freely riſe, but are abſolutely to hinder its return.

When the forcer is firſt moved upwards in the barrel, the air between that and the water below, having room to dilate, by its natural ſpring, will of courſe be rarefied; the preſſure of the atmoſphere being intercepted by the force of the barrel A B, on one hand, and by the upper valve at E in the branching-pipe on the other, the water will riſe from the ſpring into A B, for the reaſon already given; and repeated ſtrokes of the piſton will fetch up the fluid to the forcer, and fill the cavity of the pipes

pipes between the fixed valves D and E. This done, the water in this manner ſucceſſively raiſed, being hindered from going down again by the lower valve, will be preſſed by the forcer every time it deſcends, and be thereby obliged to make its way where the leaſt reſiſtance is, viz. through the upper valve at E. And whenever, on the riſing of the forcer, this preſſure intermits, the valve at E will immediately cloſe under the weight of the upper water, and prevent its return that way, while the piſton is riſing with a freſh ſupply: and this is repeated at every ſtroke of the forcer.

Deſcription of a Pump invented by M. de la Hire, which raiſes Water equally quick by the Deſcent as by the Aſcent of the Piſton in the Pump-barrel.

A A is a well, in which the lower ends of the pipes B and C are placed. D is the pump-barrel, into the lowermoſt end of which the top of the open pipe B is ſoldered, and in the uppermoſt end the hollow pipe S is ſoldered, which opens into the barrel; and the top of the pipe C is ſoldered into that piece. Each of theſe pipes has a valve on its top, and ſo have the crooked pipes E and F, whoſe lower ends are open into the pump-barrel, and their upper ends into the box G. Fig. 6.

H is the pump-handle, its center of motion is at I; and as it is moved up and down, it moves the ſolid plunger K, up and down in the barrel, by the ſtraight rod or ſpear L, which moves air-tight in a long collar of leather in the neck M; and the plunger never goes

higher than K, nor lower than D; ſo that from K to D is the length of the ſtroke.

As the plunger riſes from D to K, the atmoſphere (preſſing on the ſurface of the water A A in the well) forces the water up the pipe B, through the valve b, and fills the pump-barrel with water up to the plunger; and during this time, the valves e and S lie cloſe and air-tight on the tops of the pipes E and C.

When the plunger is up to its greateſt height at K, it ſtops there for an inſtant, and in that inſtant the valve b falls, and ſtops the pipe B at top. Then, as the plunger goes down, it cannot force the water between K and D back through the cloſe valve b, but forces all that water up through the crooked pipe E through the valve e, which then opens upward by the force of the water; and this water, after having filled the box G, riſes into the pipe N, and runs off by the ſpout at O.

During the deſcent of the plunger K, the valve f falls down, and covers the top of the crooked pipe F; and the preſſure of the atmoſphere on the well A A forces the water up the pipe C, through the valve S, which then opens upward by the force of the aſcending water; and this water runs from S into the pump-barrel, and fills all the ſpace in it above the plunger.

When the plunger is down to its loweſt deſcent at D, and ſtops there for an inſtant, in that inſtant the valve S falls down, and ſhuts the top of the pipe C; and then, as the plunger is raiſed, it cannot force the water above it back through the valve S, but drives all that water up to the

the crooked pipe F, through the valve f, which opens upward by the force of the aſcending water; which water, after filling the box G, is forced up from thence into the pipe N, and runs off by the ſpout at O.

And thus as the plunger deſcends, it forces the water below it up the pipe E; and as it aſcends, it forces the water above it up the pipe F, the preſſure of the atmoſphere filling the pump barrel below the plunger through the pipe B while the plunger aſcends, and filling the barrel with water above the plunger, through the pipe C, as the plunger goes down.

And thus there is as much water forced up the pipe N, to the ſpout O, by the deſcent of the plunger, as by its aſcent; and, in each caſe, as much water diſcharged at O as fills that part of the pump-barrel as the plunger moves up and down in.

On the top of the pipe O is a cloſe air veſſel P. When the water is forced up above the ſpout O, it compreſſes the air in the veſſel P; and this air, by the force of its ſpring acting on the water, cauſes the water to run off by the ſpout O in a conſtant and (very nearly) equal ſtream.

Whatever the height of the ſpout O be above the ſurface of the well, the top S of the pipe C muſt not be 32 feet above that ſurface; becauſe if that pipe could be entirely exhauſted of air, the preſſure of the atmoſphere in the well would not force the water up the pipe to a greater height than 32 feet: And if S be within 24 feet of the ſurface of the well, the pump will be ſo much the better.

As the collar of leathers within the neck M is apt to dry and ſhrink when the pump is not uſed, and conſequently to let air get into the pump-barrel, which would ſtop the operation of the atmoſphere in the pipe C; I think collars of old hats might be uſed inſtead of leathers, as they would not be liable to that inconvenience.

It matters little what the ſize of the pipe N be, thro' which the water is forced up to the ſpout: but a great deal depends on the ſize of the pump-barrel; and according to the height of the ſpout O above the ſurface of the well, the diameter of the bore of the barrel ſhould be as follows:

For 10 feet high the bore ſhould be 6. 9 inches; for 15 feet 5. 6; for 20 feet 4. 9; for 25 feet 4. 4; for 30 feet 4. 0: for 35 feet 3. 7; for 40 feet 3. 5; for 45 feet 3. 3; for 50 feet 3. 1; for 55 feet 2. 9; for 60 feet 2. 8; for 65 feet 2. 7; for 70 feet 2. 6; for 75 feet 2. 5; for 80 feet 2. 5 will do; for 85 feet 2. 4; for 90 feet 2. 3; for 95 feet 2. 2; and for 100 feet, the diameter of the bore ſhould not exceed 2. 1 or 2. 2 inches at moſt. If theſe proportions are attended to, a man of common ſtrength may raiſe water 100 feet high by one pump, as eaſily as he could raiſe it 10 feet high by another.

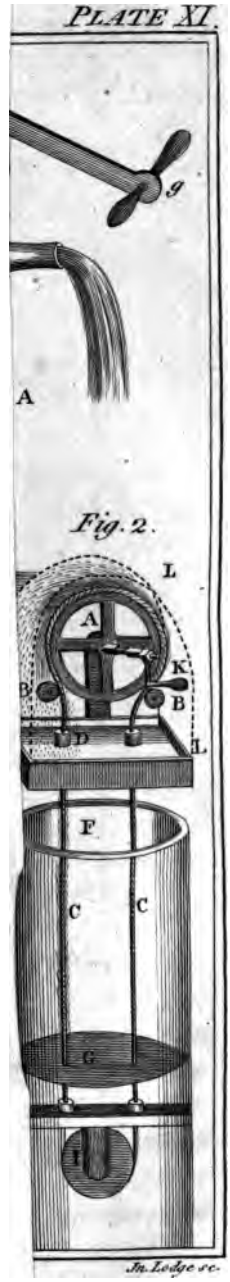
In this pump the pipes B and C ſeem to be rather too ſmall; which will cauſe the water riſing in them to have a great deal of friction from the quickneſs of its motion: and whoever makes ſuch a pump, will find it very difficult to make leathers in the neck M water-tight, ſo as that no water ſhall be forced out that way when the piſton is drawn up.

Another

Plate XI.
Fig. 1.

Fig. 2.

PLATE XI.



Another Pump, on a more ſimple Conſtruction, invented by Mr. Noble.

THIS pump deſerves notice, as it keeps a continual ſtream; being compoſed only of one ſtraight pipe, or tube, and two piſtons, having each a bucket and a valve. It raiſes as much water with the ſame power, and in the ſame time, as two barrels with four valves will do; and being ſimple in its principles, may be conſtructed reaſonable, compared with M. de la Hire's pump. Plate XI. Fig. 1.

A is a ſtraight tube, or barrel, in which two buckets work: the bucket B is worked by the rod C; and the bucket D is worked by the rod E; which rod goes thro' a hole in the bucket B, and is moved up and down by two circular pieces of wood F, fixed to two handles g g, which cauſes one bucket to aſcend with its load, and ſo *vice verſa*.

An Engine for raiſing Water by a continual Stream, by means of a Hair Rope. Invented by Sieur Vera.

A is a wheel 4 feet over, having an axis and a winch: B B, two pullies 14 inches diameter, in order to keep the ropes to a proper diſtance in the well, and be in contact with a greater ſurface of the wheel: C C, a hair-rope, near one inch diameter: D, a reſervoir to collect the water: E, a ſpout to convey the water from the reſervoir: F, the top of the well: G, the ſurface of the water in the well: H, a frame in which the lower pulley I Fig. 2.

is

is fixed: I, a pulley under which the rope runs, in order to keep it tight: K, the handle to turn the wheel: L L L, a box made of thin boards, in order to collect the water into the reſervoir D.

When the handle K is turned about with a conſiderable velocity, the water which adheres to the rope C C (in wells not very deep) is very conſiderable; the rope thus paſſes through the tube D, which, being 5 or 6 inches higher than the bottom of the reſervoir, hinders the water from returning back into the well, and is conveyed in a continual ſtream through the ſpout E. I have ſeen ſome of the above engines improved by Mr. *Stamford*, which have raiſed a greater quantity of water than any perſon unſkilled in hydraulics, could ſuppoſe in the ſame time, from ſuch a ſimple contrivance.

An Engine to raiſe Water by Fire.

The Marquis of Worceſter, in his *Century of Inventions* (printed A. D. 1663) was the firſt who propoſed raiſing great quantities of water by the force of fire, turning water into ſteam; and he mentions ſome engine of this kind which he ſaw, which played a continual ſtream, in the manner of a fountain, 40 feet high. He alſo ſays, a perſon attending it turned two cocks; that one veſſel of water being conſumed, another begins to force and refill with cold water; and this alternately and ſucceſſively, the fire being attended and kept as equal as poſſible.

Captain Savery having read this account, attempted to raiſe water by fire; and was the firſt who erected an engine for this purpoſe, of the form we have ſince had them.

them. To ſecure the invention to himſelf, he bought up all the marquis's books that he could find, and burnt them; and then gave it out that he diſcovered the method by accident. He made many experiments to bring the machine to perfection, and erected ſeveral for gentlemens ſeats; but could not ſucceed for mines, the depth from which water was to be raiſed from thence, being ſo great, that it required the ſteam too dangerouſly ſtrong to be attempted in his way.

Thus the progreſs of the engine was ſtopped till, long afterwards, Mr. Newcomen, an ironmonger, and Mr. John Cawley, a glazier, contrived another way to raiſe water by fire, where the ſteam to raiſe the water from the greateſt depths of mines is not required greater than the preſſure of the atmoſphere; and this is the preſent ſtructure of the common engine, and which is now of about 80 years ſtanding.

References to the Common Fire Engine.

A the boiler.

B the cylinder.

C the injection cock.

D the ſteam cock, or regulator.

E the ſhifting clack.

F the eduction pipe, or ſinking pipe.

G the

G the eduction valve.

H the ſafety valve.

I the piſton.

K the lever beam.

L weights to counterpoiſe the piſton, and to preſs the forcer down in the pump-barrel M, to drive the water through the pipe or ſpout N.

O a ciſtern to hold the injection water.

P an air veſſel to hinder the pipe N from burſting, and keep a regular ſtream.

Fig. 3. A is a copper veſſel, partly filled with water to d e, which being ſet over a fire and made to boil, will fill the upper part A D with a vaſtly elaſtic vapour, the ſufficient ſtrength whereof is known by its forcing open a valve at H. This heated elaſtic ſteam is, by turning a cock at D, let into the barrel B, where, by its elaſtic force, it raiſes the piſton I, which drives the air above it through a proper clack at the top. After this, that the piſton may by its weight deſcend, a little cold water from the ciſtern O, is let in at the bottom, by turning a cock at C, which, in form of a jet, condenſes the hot ſteam in the barrel into 13,000 times leſs ſpace than it took up before; which makes a ſufficient *vacuum* for the piſton to deſcend in. The piſton I and lever K, being thus put into motion, do accordingly raiſe and depreſs the piſton a, in the barrel M of the forcing pump, on the other ſide; which, by the pipe O, draws the water from the depth W, and forces it to riſe and ſpout thro' the

the tube N, continued to any height at pleaſure. This engine is uſed to draw the water from coal-pits and other mines. There are various other engines, of a more complex ſtructure; but as they act upon the ſame common principle, it is needleſs to ſay any thing more of them here.

The only improvement that has been made in the fire-engine, for thirty years paſt, the public will very juſtly attribute to the ſagacity of Mr. Watt, whoſe ſkill in pneumatics, mechanics, and hydraulics, is evinced by the powerful application of elaſtic vapour, and by making a more perfect vacuum, nearly like that of the barometer, in his new-conſtructed fire-engine.

But before I can explain Mr. Watt's engines, it is neceſſary to premiſe a ſhort account of the imperfections of the common ſteam-engines, and their cauſes.

The ſteam or vapour which ariſes from water confined in a cloſe veſſel, and heated a few degrees above the point at which it boils in the open air, becomes an elaſtic fluid, uniform and tranſparent, about half the gravity of atmoſpheric air, very much greater in bulk than the water of which it is compoſed, and capable of being again reduced to water when brought into contact with matter of a leſs degree of heat than itſelf.

The preſſure of the atmoſphere, or any equivalent reſiſtance, prevents the production of ſteam, until the water be heated to 212 degrees of Fahrenheit's thermometer; but when that preſſure is removed, or the water placed in a veſſel exhauſted of air, ſteam is produced

from it when it is colder than the human blood. On the contrary, if water be preſſed upon by air or ſteam, which are more compreſſed than the atmoſphere, a degree of heat above 212 degrees, is neceſſary for the production of ſteam; and the difference of heats at which water boils under different preſſures, increaſes in a leſs proportion than the preſſures themſelves; ſo that a double preſſure requires leſs than a double increaſe of ſenſible heat.

The experiments which have been publiſhed concerning the bulk of water when converted into ſteam, are erroneous; and the concluſions drawn from them make that bulk greater than it really is. It has been known for ſome time, that water would boil in an exhauſted receiver at a low degree of heat.

If we conſider the common ſteam-engine, we ſhall find it defective; firſt, becauſe the vacuum is produced by throwing cold water into the cylinder to condenſe the ſteam: that water becomes hot, and, being in a veſſel partially exhauſted, produces a ſteam, which in part reſiſts the preſſure of the atmoſphere upon the piſton, and leſſens the power of the engine. The ſecond defect is the deſtruction of ſteam, which unavoidably happens upon attempting to fill a cold cylinder with that fluid; for the injection-water, at the ſame time that it condenſes the ſteam, not only cools the cylinder, but remains there until it be extruded at the eduction-pipe by the ſteam which is let in to fill the cylinder for the next ſtroke; and that ſteam will be condenſed into water as faſt as it enters, until all the matter it comes in contact with be nearly as hot as itſelf.

Every

Every attempt to make the vacuum more perfect by the addition of injection-water, will cool the cylinder more effectually, and cauſe a greater deſtruction of ſteam in the next filling; and if the engine has already a proper load, the deſtruction of ſteam will proceed in a greater ratio, than the increaſe of power by the amendment of the vacuum.

Though it appears that the conſtructors of ſteam-engines have never inveſtigated theſe cauſes; yet they have been ſo ſenſible of the effects, that a judicious engineer does not attempt to load his engine with a column of water heavier than ſeven pounds for each ſquare inch of the area of the piſton.

Mr. Watt's improvement is founded upon theſe, and ſome other collateral obſervations. He preſerves an uniform heat in the cylinder of his engines, by ſuffering no cold water to touch it, and by protecting it from the air or other cold bodies, by a ſurrounding caſe filled with the ſteam or with hot air or water, and by coating it over with ſubſtances that tranſmit heat ſlowly. He makes his vacuum to approach nearly to that of the barometer, by condenſing the ſteam in a ſeparate veſſel, called the condenſer;—which may be cooled at pleaſure without cooling the cylinder, either by an injection of cold water, or by ſurrounding the condenſer with it; and generally by both. He extracts the injection-water and detached air from the cylinder or condenſer, by pumps, which are wrought by the engine itſelf; or he blows it out by the ſteam. As the entrance of air into the cylinder would ſtop the operation of the engines, and as it is hardly to be expected that ſuch enormous piſtons as thoſe of ſteam-engines can move up and down, and yet be abſo-

lutely air-tight in the common engines, a ſtream of water is kept always running on the piſton, which prevents the entry of the air; but this mode of ſecuring the piſton, though not hurtful in the common ones, would be highly prejudicial in the new engines. Their piſton is therefore made more accurately; and the outward cylinder having a lid which covers it, the ſteam is produced above the piſton; and when a vacuum is introduced under it, acts upon it by its elaſticity, as the atmoſphere does on common engines by its gravity. This way of working, effectually excludes the air from the inner cylinder, and gives the advantage of adding to the power, by increaſing the elaſticity of the ſteam.

References to the new improved Fire-Engine.

Fig. 4.

A the boiler.

B the ſafety valve.

C the pipe which conveys the ſteam to the outer cylinder.

D the outer cylinder.

E the inner cylinder.

F the piſton.

G the valve that admits the ſteam from the outer cylinder into the inner cylinder, called the ſteam-valve.

H the

H the valve that admits the ſteam from the inner cylinder into the condenſer, called the condenſing valve.

I the condenſer.

K the injection-valve that admits a jet of cold water into the condenſer to condenſe the ſteam.

L the air pump that exhauſts the condenſer both of air and the injection-water that is let in every ſtroke, and is fixed under water in the condenſing back M.

N the lever beam.

O the great water-pump for clearing the mines, or raiſing water for other uſes through the pipe P.

The internal ſtructure of the new engine ſo much reſembles the common ones, that I expect thoſe who know that machine will underſtand this, from the following deſcription;

The cylinder, the great beams, the pumps, &c, ſtand nearly in their uſual poſitions. The cylinder is ſmaller than uſual in proportion to the load, and is very accurately bored. In the moſt complete engines, it is ſurrounded at a ſmall diſtance with another cylinder, furniſhed with a bottom and lid. The interſtice between the cylinders, communicates with the boiler by a large pipe, open at both ends, ſo that it is always filled with ſteam, and thereby maintains the inner cylinder always of the ſame heat with the ſteam, and prevents any condenſation within it which would be more detrimental than an equal condenſation in the outer one.

The

The inner cylinder has a bottom and piſton as uſual; and as it does not reach up quite to the lid of the outer cylinder, the ſteam in the interſtice has always free acceſs to the upper ſide of the piſton. The lid of the outer cylinder has a hole in its middle; and the piſton rod, which is made truly cylindrical, moves up and down through that hole, which is kept tight by a collar of oakum ſcrewed down upon it.

At the bottom of the inner cylinder, there are two regulating valves; one of which admits the ſteam to paſs from the interſtice into the inner cylinder below the piſton, or ſhuts it out at pleaſure; the other opens or ſhuts the end of a pipe, which leads to the condenſer. The condenſer conſiſts of one or more pumps furniſhed with clacks and buckets (nearly the ſame as in common pumps) which are wrought by chains faſtened to the great working beam of the engine. The pipe, which comes from the cylinder, is joined to the bottom of theſe pumps, and the whole condenſer ſtands immerſed in a ciſtern of cold water ſupplied by the engine. The place of this ciſtern is either in the houſe under the floor, between the cylinder and the lever wall; or without the houſe, between that wall and the engine ſhaft, as conveniency may require.

The condenſer being exhauſted of air by blowing, and both the cylinders being filled with ſteam, the regulating valve which admits the ſteam into the inner cylinder is ſhut, and the other regulator which communicates with the condenſer is opened, and the ſteam ruſhes into the vacuum of the condenſer with violence; but there it comes into contact with the cold ſides of the pipe and pumps, and meets a jet of cold water which was opened

at

at the ſame time with the exhauſtion-regulator; theſe inſtantly deprive it of its heat, and reduce it to water; and the vacuum remaining perfect, more ſteam continues to ruſh in and be condenſed, until the inner cylinder is exhauſted. Then the ſteam which is above the piſton, ceaſing to be counteracted by that which was below it, acts upon the piſton with its whole elaſticity, and forces it do deſcend to the bottom of the cylinder, and ſo raiſes the buckets of the pumps which are hung to the other end of the beam. The exhauſtion-regulator is now ſhut, and the ſteam-one opened again; which, by letting in the ſteam, allows the piſton to be pulled up by the ſuperior weight of the pump rods: and ſo the engine is ready for another ſtroke.

The working of theſe engines is more regular and ſteady than the common ones; and, from what has been ſaid, their other advantages are apparently very conſiderable; but to ſay exactly how much they excel common engines, is difficult, as common engines differ very much among themſelves. I am told, that the ſavings amount at leaſt to two-thirds of the fuel; which is a very conſiderable object where coals are expenſive.

OPTICS.

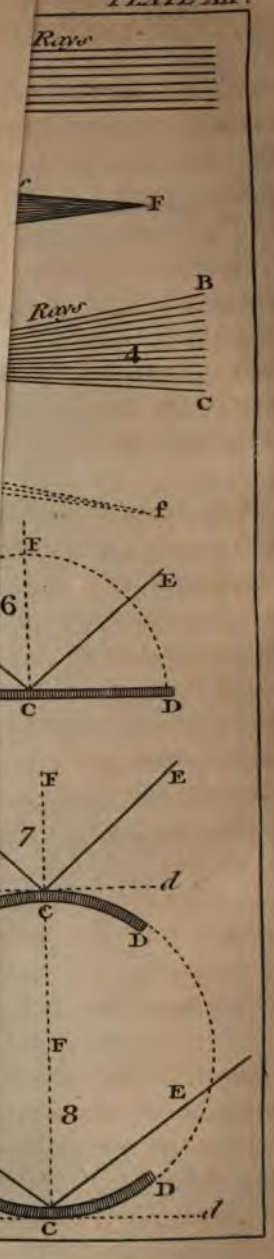
OPTICS.

AS the ſenſe of ſeeing is the nobleſt belonging to an animal; without which he would live in perpetual darkneſs, unable to perform the neceſſary exerciſes of life; and ſince all that has been demonſtrated of glaſſes, and will hereafter be demonſtrated of all optical machines, tend only to this ſingle end, to help and improve the ſenſe of ſeeing; and ſince the eye is the organ or inſtrument by which viſion is performed,—it is by nature an optical inſtrument, and the foundation of all others; and therefore it cannot be amiſs to give a ſhort deſcription thereof.

Plate XII. Fig. 1. A B C E is the eye, its figure ſpherical; by reaſon of which, it is eaſily moved any way in its ſocket. The fore-part at A is more convex than the reſt. It is contained in three membranes; the outermoſt is the *Sclerotica*; the ſecond the *Tunica Choroides*; the fore-part is called the *Iris*, which conſiſts of many fibres, like ſo many radii. The third, or innermoſt, is called the *Retina*; which is nothing but the optic nerve, ſpread over the bottom of the eye.

In theſe are contained the three humours of the eye; the firſt is H A I, called the *Aqueous* humour, which is a thin

PLATE XII.



thin liquor like water. The ſecond is F G the *Chryſtalline*, in form of a lens, more convex behind towards C. Adjoining to this is the third, K L, called the *Vitreous* humour.

The chryſtalline is more denſe than the vitreous, and the vitreous more denſe than the aqueous humour, and all together make a compound lens, which refracts the rays of light, iſſuing from an object P R, to the bottom of the eye, and there paints its image p r in the focus upon the retina inverted.

The figure of the aqueous humour is a meniſcus, and ſo is that of the vitreous. The fore part of the ſclerotica is called the *Cornea*, and that part adjoining to it, is called the *White* of the eye. Within the cornea is a coat called the *Uvea*; in the middle of this is a hole O, called the *Pupil*, to let in the rays of light. And the pupil is contracted or dilated by ſeveral muſcular fibres in the uvea or iris, according as more or leſs light falls on the eye, and that by an involuntary motion.

D is the optic nerve going from the retina to the common ſenſorium in the brain, where theſe images are perceived. This is not in the middle of the eye, but lies nearer the ſide E, which is towards the noſe.

Round the edge of the chryſtalline F G is a ring of fibres; by the help of which the diſtance A C is made longer or ſhorter, in order to bring the image p r upon the retina, for diſtinct viſion. And perhaps theſe fibres alſo make the chryſtalline more or leſs con-

vex at the ſame time. This ring of fibres is called the *Ligamentum ciliare*; and its back part is black, to ſtifle the rays that are reflected upon it.

The eye is moved in the head by ſeveral muſcles inſerted in the ſclerotica, ſo that it may be quickly directed to any object.

If the image of an object does not fall upon the retina, at p r, the viſion will be confuſed. If it falls ſhort, or nearer F G, then a concave lens that makes the rays more diverging, will bring them to the retina. This is the caſe of purblind or ſhort-ſighted people, who are forced to look very near an object; or elſe they muſt uſe concave ſpectacles.

If the rays do not unite till they get beyond the retina, as in moſt old people, then a common convex lens of a due force, held between the eye and the object, will make them converge, and fall upon the retina. Therefore long-ſighted people muſt uſe convex ſpectacles.

Although the image is painted inverted in the eye, yet we judge it erect; becauſe we always find it ſo by cuſtom and experience.

But that viſion is effected in this manner, may be demonſtrated experimentally. Take a bullock's eye while it is freſh, and having cut off the three coats from the back part, quite to the vitreous humour, put a piece of white paper over that part, and hold the eye towards any bright object, and you will ſee an inverted picture of the object upon thepaper.

Seeing

Seeing the image is inverted, many have wondered why the object appears upright. But we are to conſider, 1. That inverted is only a relative term: and, 2. That there is a very great difference between the real object and the means or image by which we perceive it. When all the parts of a diſtant proſpect are painted upon the retina, they are all right with reſpect to one another, as well as the parts of the proſpect itſelf; and we can only judge of an object's being inverted, when it is turned reverſe to its natural poſition, with reſpect to other objects which we ſee and compare it with. If we lay hold of an upright ſtick in the dark, we can tell which is the upper or lower part of it, by moving our hand upward or downward; and know very well that we cannot feel the upper end by moving our hand downward. Juſt ſo we find by experience, that upon directing our eyes towards a tall object, we cannot ſee its top by turning our eyes downward, nor its foot by turning our eyes upward; but muſt trace the object the ſame way by the eye to ſee it from head to foot, as we do by the hand to feel it: and as the judgment is informed by the motion of the hand in one caſe, ſo it is alſo by the motion of the eye in the other.

The diameters of images at the bottom of the eye, as p r, are proportioned to the angles which the objects ſubtend at the eye, as P O R; the ſame as in a lens; and are reciprocally as the diſtances of the ſame object viewed in different places.

The eye is in reality no more than a camera obſcura; for the rays of light flowing from all points of an object, through the pupil of the eye, do, by the refraction of the humours of the eye, paint the image thereof in

8th. A man can judge at a ſmall diſtance with a ſingle eye, by frequently obſerving how much variation is made in the eye to make the object diſtinct; and from this, a habit of judging is acquired. But this cannot be done at great diſtances, becauſe, though the diſtance be varied, the chance in the eye becomes then inſenſible.

9th. But a man can judge of greater diſtances with both eyes, than he can with one eye. For the eyes being at a diſtance from one another, as long as that diſtance has a ſenſible proportion to the diſtance of the object, one gets a habit of judging, by the poſition of the axis of the eyes, which are always directed to that point; for different diſtances require different poſitions of the axis, which depends on the motions of the eyes which we feel. But in very great diſtances, no judgment can be made from the motion of the eyes, or their internal parts. Therefore, we can only gueſs at the diſtances from the magnitude, colour, and the poſition of interjacent bodies.

10th. Whatever light falls upon that part of the retina where the optic nerve D ſprings, makes no impreſſion; and therefore, if the picture of an object falls thereon, it is not perceived, and that object is inviſible. This will appear by placing a ſmall bright object before you, and looking at it with one eye; and moving one eye laterally towards the contrary ſide (towards the left, if it be the right eye) the object will diſappear, and ſeem to be loſt; and moving it ſtill further, it will appear again. Now this place is not at the bottom of the eye, but nearer the noſe in both of them; ſo that no rays, either parallel or diverging, that come from any object,

can

can fall upon that place in both the eyes; ſo that any object we direct the eyes to, will always be viſible, at leaſt to one eye. But the ſame bright object may be made to diſappear to both eyes, by directing the axis of both eyes to a point a little beyond the noſe, to be found by trials.

11th. Dimneſs of ſight generally attends old people; and this may ariſe from two cauſes: 1, By the eyes growing flat, and not uniting the rays at the retina, which cauſes indiſtinctneſs of viſion; or, 2. By the opacity of the humours of the eye, which in time loſe their tranſparency in ſome degree; from whence it follows, that a great deal of the light is ſtopt and loſt that enters the eye; and every object appears faint and dim.

12th. As the rays of light flowing from an object, and painting its image upon the retina, are the immediate cauſe of ſeeing, ſo where there is no light, there can be no viſion: conſequently, without light, the eye becomes a machine utterly uſeleſs; as it can give us no manner of information of the exiſtence of bodies at a diſtance from us.

DEFINITIONS.

1. OPTICS is a ſcience which teaches the nature, properties, and laws of *Viſion*, ariſing from the rays of light, either *reflected* from the ſurfaces of bodies, or refracted in paſſing through them, and painting the images of objects on the *Retina* on the bottom of the eye. Alſo this ſcience, in its moſt extenſive acceptation, comprehends the whole doctrine of *Light* and *Colours*, and all the *Phænomena* or appearances of viſible objects.

objects. Optics, therefore, conſiſt of three parts, *viz.* *Catoptrics*, *Dioptrics*, and *Chromatics*.

2. *Catoptrics* is that part which treats of *Reflex Viſion*, or all that relates to the viewing of objects by light, *reflected* from the ſurfaces of bodies, whether *plain*, *convex*, *concave*, or otherwiſe; and in rays *diverging*, *converging*, or *parallel* to each other.

3. *Dioptrics* treat of the properties of light and viſion, ariſing from rays paſſing through tranſparent *Media*, or bodies; as *Air*, *Water*, *Glaſs*, *Chryſtal*, *Diamond*, &c.

4. *Chromatics* treat of the *Colours* of light and natural bodies. Of this part, Sir *Iſaac Newton*'s Optics almoſt entirely conſiſt.

5. *Light* is that property of ſome bodies, by which objects are rendered *viſible*, or capable of being *ſeen* by the eye. It conſiſts of very ſmall particles, which iſſue from the luminous body in ſtraight lines.

6. *Rays* or *Beams* of light, are thoſe ſtreams, or emanations of light, which proceed from the luminous body, and enlighten or illuminate all objects, ſo that they may be ſeen.

7. The *Radient* is that body or object which emits, or from which proceeds the rays of light under conſideration at any time.

8. The *Species* of an object is the image or repreſentation thereof, made by the rays of light in the *Focus*, or place where they unite.

9. *Parallel*

9. *Parallel* rays, are ſuch as proceed *equally diſtant* from each other through all their courſe; as thoſe from the *Sun*, and other vaſtly diſtant objects. Fig. 2.

10. *Converging* rays are ſuch as, proceeding from a body, approach nearer and nearer together in their progreſs, tending to one certain point, where they all unite; thus the rays, proceeding from the object A B to the point F, are ſaid to *converge* towards that point. Fig. 3.

11. *Diverging* rays are thoſe which, proceeding from any point, as A, do continually recede from each other as they paſs along in their courſe towards B C. Fig. 4.

12. The *Focus* of *Rays* is that point to which all converging rays tend, and in which they unite and interſect each other; as the point F. And this is called the *Real* Focus; but, Fig. 3.

13. The *Virtual* or *imaginary Focus*, is a point, as f, to which the rays A B tend, and where they would unite, were they not intercepted by the obſtacle (ſuppoſe a mirror) C D; by which means they are turned aſide, and made to converge in their *Real Focus* F. Fig. 5.

14. *Reflection* of rays is their *Regreſs* or *Returning* from the ſurface of ſuch bodies on which they fall, and cannot penetrate or enter. Thus the ray B C falling on the ſurface A D, is reflected or turned back or up again in the direction C E. Fig. 6.

15. The *Plane* of *Reflection* is that in which the reflecting point, or ſurface, is ſituated, as A D and a d, Fig. 7, 8.

Fig. 6. 16. *Mirrors*, or *Speculums*, are thoſe bodies whoſe ſurfaces are ſo very ſmooth, and fine poliſhed, as to be impervious to the rays of light which fall on them, and which, therefore, they reflect ſo entirely, as to repreſent the *Images of Objects* oppoſed to them. Theſe are generally made of metal, or glaſs, poliſhed on one ſide, and ſilvered on the other, and are either *plain*, *convex*, or *concave*.

17. *Plain Mirrors* are thoſe whoſe ſurfaces are perfect *Planes*, and whoſe ſection is a *ſtraight Line*, as A. D. Note, Theſe are vulgarly called *Looking-Glaſſes*.

18. *Convex Mirrors* are ſuch whoſe ſurface do every way equally and uniformly riſe above the plane of their baſes or loweſt parts; the ſection of which ſorts of mirror is a *Curve*, either *Circular*, *Elliptical*, *Paraboli-*
Fig. 7. *cal*, or *Hyperbolical*. Where A C D is a *Circular* ſection, and the *Mirror* is the ſegment of a *Globe*, or *Spherical* ſurface, which are moſt of common uſe. As,

19. *Concave Mirrors* are thoſe whoſe ſurfaces ſink down with an uniform hollowneſs or curvity below the
Fig. 8. upper parts A D, and whoſe ſection alſo is a *Curve*, as various as the convex above; but A D is circular, and its ſurface the internal part of an *hollow Sphere*, as being moſt in uſe.

20. The *Incident Ray* is that which comes from any object, and falls on the reflecting ſurface, as B C; and C E is the *reflected Ray*. Fig. 6.

21. The *Angle* or *Incidence* is that which is contained between the *incident Ray* B C, and a perpendicular to the

the reflecting ſurface in the point of reflection F C; *viz.* the angle B C F. Fig. 6, 7, 8.

22. The *Angle of Reflection* is that contained between the ſaid perpendicular F C, and the reflected ray C E; *viz.* the angle F C E. Fig. 6, 7, 8.

23. *Refraction* of rays is their being bent or turned out of their firſt courſe, in paſſing out of one *Medium* into another. Let A D H I be a body of *Water*, A D its ſurface, C a point in which a ray of light B C (in the air) begins to enter the ſame: this ray by the greater denſity of the water, will be reſiſted, and inſtead of paſſing ſtraight forwards in its firſt direction to K, it will be bent therefrom, and made to deſcribe the tract C E, which is called the *refracted Ray*. Let F G be drawn perpendicular to the ſurface of the medium in C, then it is plain the ray B C, in paſſing out of a *rarer Medium* (*viz.* of *Air*) into a *denſer Medium*, (*viz.* of *Water*) is refracted into a ray C E, which is nearer to the perpendicular C G, than the *incident Ray*; and on the contrary, the ray E C paſſing out of a *denſer* into *a rarer Medium*, will be refracted into C B, which is farther from the perpendicular. Fig. 9.

24. The *Angle* B C F is the angle of *Incidence*, as before; and F C E is the angle of *Refraction*, as being contained between the refracted ray C K, and the perpendicular C G.

25. A *Lens* is a medium, generally of *Glaſs*, of a proper form to *collect* or *diſperſe* the rays of light which paſs through it. Of theſe, there are various forms, which, from thence, receive divers names. As,

Fig. 10. 26. A *Plano-Convex*, which hath one ſide plain, the other ſpherical, or convex; as A.

27. A *Plano-Concave*, plain on one ſide, and concave on the other; as B.

28. A *Double-Convex*, is one *Convex* on both ſides; as C.

29. A *Double-Concave*, is one *Concave* on both ſides; as D.

30. A *Meniſcus*, is one *Convex* on one ſide, and *Concave* on the other; as E.

31. A *Plain Glaſs*, which is flat on both ſides, and of equal thickneſs in all its parts; as F.

32. A *Flat Plano-Convex*, whoſe convex ſide is ground into ſeveral flat ſurfaces; as G.

33. A *Priſm*, with three flat ſides, and when viewed endways, appears like an aquilateral triangle; as H.

34. Glaſſes ground into any of the ſhapes A B C D E, are called lenſes; and a line going horizontally through the middle, I K, is called the axis of the lens.

Fig. 11. 35. The *Vertex* of a *Mirror*, or *Lens*, as A B, is the middle point V, every way equally diſtant from its baſe,

36. The

36. The *Axis* of a *Mirror*, or *Lens*, is the right line E D, drawn through the vertex V, and the center C, on which it was deſcribed.

37. The *Viſual* or *Optic Angle*, is that which is contained under the two right lines drawn from the extreme points of an object to the eye; thus A E B or C E D is the *Optic Angle*, or that under which the object A B or C D appears to the eye at E. Fig. 12.

38. A *Pencil* of rays is a double cone of rays, as L O N F L, joined together at the baſe in the *Lens* L N; of which one cone L O N has its vertex in ſome point of an object, as at O; and the other cone L F N has its vertex in the point of convergence, or *Focus* F. The middle line O F is called the *Axis* of that pencil. Fig. 13.

Of the Practical Part of Optics, with as much Theory as will be ſufficient for the Conſtruction and Uſe of moſt Kinds of Optical Inſtruments.

WHAT I here propoſe to lay down as the practical part of optics, is chiefly intended for thoſe whoſe curioſity and ingenuity may lead them to make farther diſcoveries in this noble ſcience.

The part of optics has always been kept as ſecret as poſſible by people who made it their buſineſs; and the prices of optical inſtruments being partly out of the reach of any, but ſuch as are poſſeſſed of independent fortunes; by this means, ſome thouſands of ingenious enquirers have been deprived from viewing the glorious works

works of Nature, which afford ſuch an amazing field for contemplation and amuſement.

It has been attended with great expence, and unwearied diligence for me to gain the little knowledge I have of this art, and which I ſhall freely communicate to the public in as plain a manner as I poſſibly can. In order to do this, I ſhall deſcribe the parts, as far as the conſtruction and uſe require, of every machine I ſhall have occaſion to treat of; at the ſame time I would particularly recommend to every one who wiſhes to make ſome proficiency in opties, to a cloſe application to the mathematics, as that is the only means whereby any one can attain a true knowledge of its theory.

My deſire is alſo to make people ſenſible of the pleaſure and information the microſcope and teleſcope can afford, and inſtruct them how to manage as well as to make theſe machines; likewiſe explain the effects of glaſſes on the ſight, and lead them gradually into the nature, uſe, and magnifying powers of theſe inſtruments.

Of Spectacles.

WHEN objects are ſeen through a perfectly flat glaſs, the rays of light paſs through it, from them to the eye, in a ſtraight direction, and parallel to each other; and conſequently, the objects appear very little either diminiſhed or enlarged, or nearer or farther off, than to the naked eye. But if the glaſs they are ſeen through has any degree of convexity, the rays of light are directed from the circumference towards the center, in an angle proportionable to the convexity of the glaſs,

glaſs, and meet in a point, at a greater or leſſer diſtance from the glaſs, as it is more or leſs convex. This point, where the rays meet, is called the Focus; and this focus is nearer or farther off, according to the convexity of the glaſs; for as a little convexity throws it to a conſiderable diſtance, ſo when the convexity is much, the focus is very near. Its magnifying power is alſo in the ſame proportion to the convexity: for as a flat glaſs ſcarce magnifies at all, the leſs a glaſs departs from flatneſs, the leſs of courſe it magnifies; and the more it approaches towards a globular figure the nearer its focus is, and the more its magnifying power.

People's different length of ſight depends on the ſame principle, and ariſes from a more or leſs convexity of the cornea and chryſtalline humour of the eye; the rounder theſe are, the nearer will the focus or point of meeting rays be, and the nearer an object muſt be brought to ſee it well. The caſe of ſhort-ſighted people is only an over-roundneſs of the eye, which makes a very near focus; and that of old people is a ſinking or flattening of the eye, whereby the focus is thrown to a great diſtance: ſo that the former may properly be called eyes of too ſhort, and the latter eyes of too long a focus. Hence too, the remedy for the laſt is a convex glaſs, to ſupply the want of convexity in the eye itſelf, and brings the rays to a ſhorter focus; whereas a concave glaſs is needful for the firſt, to ſcatter the rays, and prevent their coming to a point too ſoon.

Nothing is more common than to obſerve old people holding objects they would examine at a great diſtance from them, for the reaſon above mentioned; and every body

body knows, ſhort-ſighted people cannot diſtinguiſh any thing without bringing it very near their eyes. Both extremes are very inconvenient; but thoſe whoſe eyes are flat by age, ſhould remember with ſatisfaction, that they have enioyed the pleaſure of them for many years; and the ſhort-ſighted may comfort themſelves, that they can diſtinguiſh much ſmaller objects than long-ſighted people: for the object is magnified in proportion to the roundneſs of the eye, and the nearneſs of the focus, and conſequently appears four times as big to an eye whoſe focus is but four inches off, as it does to one whoſe focal diſtance is at eight inches. Short-ſighted people have alſo this farther advantage, that age improves their eyes, by the ſame means it impairs other people's, that is by making them more flat.

The nearer any object can be brought to the eye, the larger will be the angle under which it appears, and the more it will be magnified. Now, that diſtance from the naked eye, where the generality of people are ſuppoſed to ſee ſmall objects beſt, is at about ſix inches; conſequently, when ſuch objects are brought nearer than ſix inches, they will become leſs diſtinct: and if to four or three, they will ſcarce be ſeen at all. But by the help of convex glaſſes we are enabled to view things clearly at much ſhorter diſtances than theſe: for the nature of a convex lens is to render an object diſtinctly viſible to the eye at the diſtance of its focus; wherefore the ſmaller a lens is, and the more its convexity, the nearer is its focus, and the more its magnifying power.

Plate XIII. Fig. 1. Now, it is evident, from the figure, if either the cornea, a b c, or chryſtalline humour e, or both of them, be the

PLATE XIII.

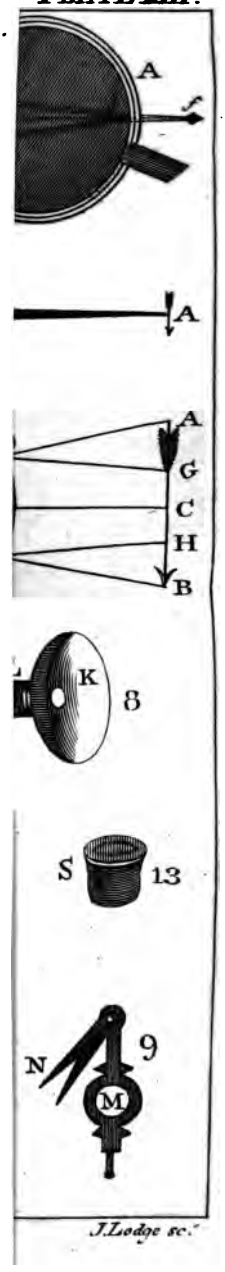


Plate XII
Fig. 1.

too flat, as in the eye A, their focus will not be on the retina, as at d, where it ought to be, in order to render vision diſtinct; but beyond the eye, as at f. Conſequently thoſe rays which flow from the object C, and paſs thro' the humours of the eye, are not converged enough to unite at d; and therefore the obſerver can have but a very indiſtinct view of the object. This is remedied by placing a convex glaſs g h, of a proper focus, before the eye; which makes the rays converge ſooner, and imprints the image duly on the retina at d.

If either the cornea or chryſtalline humour, or both of them, be too convex, as in the eye f, the rays that enter in from the object C, will be converged to a focus in the vitreous humour, as at f, and by diverging from thence to the retina, will form a very confuſed image thereon; and ſo, of courſe, the obſerver will have as confuſed a view of the object as if his eye had been too flat. This inconvenience is remedied by placing a concave glaſs g h, before the eye; which glaſs, by cauſing the rays to diverge between it and the eye, lengthens the focal diſtance ſo, that if the glaſs be properly choſen, the rays will unite at the retina, and form a diſtinct picture of the object upon it.

When glaſſes are put in frames for ſpectacles, their frames ought not to be ſtraight, ſo as both eyes may be as the ſame plane; but they ought to be ſo bent in the middle, that the axis of both glaſſes may be directed to one point, at ſuch a diſtance as you generally look with ſpectacles. By this means the eyes will fall perpendicular upon both glaſſes, and make the object appear diſtinct. But if they fall obliquely upon the glaſſes, it will cauſe a confuſed appearance in the objects; therefore, the ſhape of the frame ought to be as repre-

Fig. 2. ſented when A B is the plane as one glaſs is fixed, and C D the other.

Spectacles are the moſt uſeful optical machine in the world. There are few people that grow into years but have occaſion for them to help their defective eyes; and without them would be uſeleſs in a great many occaſions of life.

OF MICROSCOPES.

THE word Microſcope imports an inſtrument for viewing ſeveral ſmall objects. I have before obſerved, that Nature has ſo formed the human eye, that we cannot diſtinctly view an object at a nearer diſtance than ſix inches: and ſince there is an affinity of objects which at that diſtance appear either as points, or are wholly imperceptible, whatſoever inſtrument or contrivance will render ſuch minute objects viſible and diſtinct, we properly call a Microſcope.

It is uſual to ſay, that the microſcope magnifies objects ſeen through it; but this is true only with regard to the apparent, not the real magnitude of objects; they indeed appear to be larger with than without a microſcope; but in truth they are not; and the reaſon why they appear to be magnified will be eaſy to apprehend, by any perſon who underſtands the nature of the optic angle.

The apparent magnitude of objects is meaſured by the angle which they are ſeen under by the eye; and thoſe angles are reciprocally as the diſtances from the eye. If therefore at the diſtance of ſix inches, I can but juſt diſcern an object, and then by the interpoſing a lens,

lens, or other body, I can come to view that very object at a nearer diſtance, the object will appear to be as much larger through the lens than before to the naked eye, as its diſtance from the lens is leſs than its diſtance from the eye.

That this is the caſe is evident, from where A is a point in an object not clearly viſible to the naked eye, at a leſs diſtance than A B, becauſe the rays which proceed from it are too divergent to admit of diſtinct viſion till they have paſſed that diſtance; but if the ſame object be placed in the focus C of the lens D, the rays which proceed from it will become parallel, by paſſing thro' the ſaid lens, and therefore the object is diſtinctly viſible to the eye E, placed anywhere before the lens D. Conſequently it will appear as much larger through the lens than to the naked eye, as C D is leſs than A B. Fig. 3.

If an object A B be placed in one focus C of a lens D E, and the eye in the other focus F, the eye will ſee juſt ſo much of the object as is equal to the diameter of the lens; for the rays of A D and B E, which go from the object to the extremities of the lens D and E, and are united at the focus F, muſt neceſſarily proceed from the object to the lens parallel to the axis F C, and therefore parallel to each other; conſequently the part of the object A B, ſeen by the rays D F, E F, will be equal to the diameter D E of the ſaid lens. Fig. 4.

If only the part d e of the lens be open, then only ſo much of the object a b, as is equal thereto, will be perceived by the eye. Now ſince A B is equal to D E, or a b to d e, therefore the angle D F E, or d F e, is the

optic angle under which the part of the object A B or a b appears to the eye at F; and ſince G F is but one half F C, therefore the angle D F E, or d F e, is double to that under which the part A B or a b would appear to the naked eye at the diſtance F C; that is, the eye ſees the object ſituate as above, twice as large with the lens as it would do without it.

If you would ſee a portion of an object larger than the lens, your eye muſt be placed nearer the lens than its focus. Let the lens be D E, its two foci F and C; in the focus C let there be an object A B larger than the lens; ſuppoſe the rays A D, B E, proceed from the extremities of the object to thoſe of the lens, it is evident from the figure they will be convergent, and therefore will by the lens be united in a point K, between the lens D E, and its focus F: if then the eye be placed at K, it will take into its view an object greater than the lens D E.

Fig. 5.

Again, let G H be a portion of an object A B, leſs than the lens D E; draw G D, H E, which will be diverging rays, and therefore will be united at a point I, farther diſtant from the lens than the focus F: hence, if an eye be placed farther from the lens than its focal diſtance, it can never ſee any object, or part of an object, at one view, ſo large as the lens, but always ſmaller. And univerſally, the viſible part of an object will be to the lens as the focal diſtance of the lens to the diſtance of the eye.

Since then it is evident the nature of a convex lens is ſuch as will render an object diſtinctly viſible to the eye at the diſtance of its focus, the reaſon why they are

are uſed as microſcopes is exceeding plain. For ſuppoſe the diſtance A B be ſix inches, where the naked eye B can but juſt perceive the object A diſtinctly, and let the focal diſtance C D of the lens D be half an inch; then ſince C D is but one-twelfth of A B, the length of the object at C will appear twelve times as large as at A: if it were a ſurface, it would be one hundred and forty-four times as great; and the ſolidity or bulk would be magnified one thouſand ſeven hundred and twenty-eight times.

If C D, the focal diſtance of the lens D, be but one-fourth part of an inch, then will that be but 1-24th of A B, equal ſix inches, and ſo the length of objects will be magnified twenty-four times; the ſurface five hundred and ſeventy-ſix times, and the ſolidity thirteen thouſand eight hundred and twenty-four times; for thoſe numbers are the ſquare and cube of twenty-four. From whence it appears, that ſingle glaſs lenſes make very good microſcopes, which have theſe advantages, that the object appears moſt clear, they lie in little room, may be carried about anywhere, are to be had for a ſmall price, and are moſt eaſy to be uſed.

The form of a very convenient microſcope, is where A B is a circular piece of wood, ivory, &c. in the middle of which is a ſmall hole, 1-20th of an inch diameter: upon this hole is fixed, with a wire, a ſmall lens C, whoſe focal diſtance is C D. At that diſtance is a pair of plyers D E, which may be adjuſted by means of the ſliding ſcrew, as in the figure, and opened by means of the two little ſtuds a e; with theſe you take up any ſmall object O, and view it with the eye placed in the other focus of the lens at F; and according to the focal length Fig. 6.

length of the lens, the object O will appear more or leſs magnified, as repreſented at I M. If the focal length be half or ¼th of an inch, the length, ſurface, and bulk of the object will be magnified as before deſcribed. This ſmall inſtrument may be put into a caſe, and carried about in the pocket without any incumbrance. I have made trial of various lenſes, and find thoſe whoſe focal lengths are 3-10ths, 4-10ths, and 5-10ths of an inch, the beſt for common uſe.

Since the nearer the eye can approach to an object, the larger it appears, it is plain a double and equally convex lens is far preferable to a plano-convex lens; becauſe if the ſphere or convexity be the ſame, the focal length of the former is but half as long as of the latter: and ſince the double convex conſiſts of two ſegments of a ſphere, the more an object is to be magnified, the greater muſt the convexity be, and therefore the ſmaller the ſphere; till at laſt the utmoſt degree of magnifying will require that theſe ſegments become hemiſpheres, and conſequently the lens will be reduced to a perfect ſpherule, or very ſmall ſphere.

If the radius of the ſpherule be 1-10th of an inch, the eye will have diſtinct viſion of an object by means thereof, at the diſtance of 1½ radius; *i. e.* 3-20ths of an inch, which, as it is but the 40th part of ſix inches, ſhews that the length of an object will be magnified forty times, the ſurface one thouſand ſix hundred times, and the ſolidity ſixty-four thouſand times, by ſuch a ſmall ſphere.

If the radius of a ſpherule be but 1-20th of an inch, then will the eye have diſtinct viſion of an object at the diſtance of 3-40ths of an inch, which, as it is but the

the 80th part of ſix inches, ſhews the length of objects will appear 80 times greater, the ſurface 6,400 times, and the bulk 512,000 times greater to the naked eye at ſix inches diſtance.

Again, if the diameter of a ſpherule be 1-20th of an inch, or the radius 1-40th, then will the eye approach the object ſo near as the 3-80th part of an inch, which is but the 160th part of ſix inches; and therefore the length of objects will be magnified 160 times, the ſurface 25,600 times, and the ſolidity 4,096000 times by this ſpherule; which is ſo great a power of magnifying, as ſurpaſſes all human imagination and comprehenſion.

In uſing theſe ſpherule microſcopes, the objects are to be placed in one focus, and the eye in the other; and ſince the focus is ſo exceeding near the glaſs, it is impoſſible to view any but pellucid bodies; for if any opaque object were to be applied, the eye being, as it were, juſt on the ſpherule, would entirely prevent any light falling on it, and it would be too obſcure to be viewed.

It was with this ſort of microſcopes that the famous Dutch philoſopher, Mr. Leeuwenhoek made ſuch wonderful diſcoveries; and it muſt be with theſe, if with any, that the corpuſcles or atoms, of which bodies conſiſt, are to be diſcovered; which the great Sir Iſaac Newton thought was poſſible. But the great difficulty of making very ſmall and at the ſame time very good ones; their prejudice to the eyes, in poring very hard and near; the trouble of placing objects at a due diſtance, and the very ſmall part which can be ſeen of

any,

any, make this ſort of microſcopes very little known or uſed.

Of a Single Microſcope for Opaque Objects.

THIS microſcope remedies the inconvenience of having the dark ſide of an object next the eye, which has hitherto been an unſurmountable obſtruction to the making obſervations on opaque objects with any conſiderable degree of exactneſs or ſatisfaction; for in all other contrivances commonly known, the nearneſs of the inſtrument to the object (when glaſſes that magnify much are uſed) unavoidably overſhadows it ſo much, as to render its appearance obſcure and indiſtinct: and, notwithſtanding, ways have been tried to point light upon an object from the ſun, or a candle, by a convex glaſs placed on the ſide thereof; the rays from either can be thrown upon it in ſuch an acute angle only, that they ſerve to give a confuſed glare, but are inſufficient to afford a clear and perfect view of the object.

But in this new microſcope, by means of a concave ſpeculum of ſilver, highly poliſhed, in whoſe center a magnifying lens is placed, ſo direct and ſtrong a light is reflected upon the object, that it may be examined with all imaginable eaſe and pleaſure.

The apparatus for this purpoſe has afforded me more delight and ſatisfaction than I am able to deſcribe; and whoever tries it, will, I believe, join in my opinion, that he never ſaw an opaque object with ſo much clearneſs, and in ſo perfect and true a manner.

The

The ſeveral parts of this inſtrument, commonly made of braſs, are as follow:

Through the firſt ſide A, paſſes a fine ſcrew B, the other end whereof is faſtened to the moveable ſide C. Fig. 7.

D is a nut adapted to the ſaid ſcrew, by the turning of which the two ſides A C are gradually brought together.

E is a ſpring of ſteel, that ſeparates the ſaid two ſides when the nut is unſcrewed.

F a piece of braſs turning round in a ſocket, whence proceeds a ſmall ſpring-tube, moving upon a rivet, through which tube there runs a ſteel wire, one end whereof terminates in a ſharp point G, and the other hath a pair of plyers H faſtened to it. The point and plyers are to thruſt into or to take up and hold any inſect or object: and either of them may be turned upwards, as ſuits your purpoſe beſt.

I is a ring of braſs with a female ſcrew within it, mounted on an upright piece of the ſame metal, which turns round on a rivet, that it may be ſet at a due diſtance when the leaſt magnifiers are employed. This ring receives the ſcrews of all the magnifiers.

P a handle turned of wood, to ſcrew into the inſtrument when it is made uſe of.

K a concave ſpeculum of ſilver, poliſhed as bright as poſſible, in the center of which a double convex lens is placed, Fig. 8.

placed, with a proper aperture to look through it. On the back of this ſpeculum a male ſcrew L is made to fit the braſs ring I, to ſcrew into the ſaid ring at pleaſure.

There are four of theſe concave ſpecula, of different magnifying powers, to be uſed as objects to be examined may require. The greateſt magnifiers muſt always have the leaſt apertures.

Fig. 9. M a round object-plate, one ſide white and the other black, intended to render objects the more viſible, by placing them, if black, on the white, and if white on the black ſide. A ſteel ſpring N, turns down on each ſide to make any object faſt: and iſſuing from the object plate is a hollow pipe, to ſcrew it on the needle's point G.

Fig. 10. O is a ſmall box of braſs, with a glaſs on each ſide, contrived to confine any living object, in order to examine it: this alſo has a pipe to ſcrew upon the end of the needle G.

Fig. 11. Q a pair of braſs plyers, to take up any object, or manage it with conveniency.

Fig. 12. R a ſoft hair-bruſh, to clean the glaſſes or ſpecula, or apply a drop of any liquid to the iſinglaſs of the box O, in order to view the animalcules.

Fig. 13. S a ſmall ivory box for the talcs, to be placed when wanted in the ſmall braſs box O.

Fig. 7. When you would view any object, ſcrew the ſpeculum, with the magnifier you would think beſt to uſe, into

into the braſs ring I. Place your object either on the needle G, in the plyers H, on the object-plate M, or in the braſs hollow box O, as may be moſt convenient, according to the nature and condition of it: then, holding up your inſtrument by the handle P, look againſt the light, through the magnifying lens, and by means of the nut D, together with the motion of the needle, by managing its lower end, the object may be turned about, raiſed, or depreſſed, brought nearer the glaſs, or put farther from it, till you hit the true focal diſtance, and the light be ſeen reflected from the ſpeculum ſtrongly upon the object; by which means, it will be ſhewn in a manner ſurprizingly diſtinct and clear. And for this purpoſe, the light of the ſky, or of a candle, will anſwer to your ſatisfaction.

This microſcope is principally intended for opaque objects, but tranſparent ones may alſo be viewed by it: obſerving only, that when ſuch come under examination, it will not always be proper to throw on them the light reflected from the ſpeculum: for the light tranſmitted through them meeting the reflected light, may, together, produce too great a glare. A little practice will teach how to regulate both theſe lights to good advantage.

There is reaſon to expect great diſcoveries may be made by the apparatus above deſcribed, as opaque objects are a large field, but little hitherto examined, by reaſon of the great difficulty in doing it.

Of Mr. Wilſon's ſingle Pocket Microſcope.

THE body is made either of braſs, ivory, or ſilver, as repreſented A A B B.

Plate XIV. Fig. 1.

C C is a long fine-threaded male ſcrew, that turns into the body of the microſcope.

D a convex glaſs at the end of the ſaid ſcrew.

1. Two concave round pieces of thin braſs, with holes of different diameters in the middle of them, to cover the ſaid glaſs, and thereby diminiſh the aperture when the greateſt magnifiers are employed.

E E three thin plates of braſs within the body of the microſcope, one whereof is bent ſemicircularly in the middle, ſo as to form an arched cavity for the reception of a tube of glaſs, whereas the two flat plates are to receive and hold the ſliders between them.

F a piece of wood or ivory, arched in the manner of the ſemicircular plate, and cemented thereto.

G the other end of the body of the microſcope, where a hollow female ſcrew is adapted to receive the different magnifiers.

H a ſpiral ſpring of ſteel, between the ſaid end C and the

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J. Hodges Sc.

the plates of braſs; intended to keep the plates in a right poſition, and counteract againſt the long ſcrew C C.

I a ſmall turned handle, for the better holding of the inſtrument, to ſcrew on or off at pleaſure.

To this microſcope belong ſeven different magnifying glaſſes: ſix of them are ſet in ſilver, braſs, or ivory, as in K, and marked 1, 2, 3, 4, 5, 6, the loweſt numbers being the greateſt magnifiers. Fig. 2.

L is the ſeventh magnifier, ſet in the manner of a little barrel, to be held in the hand for the viewing any larger object. Fig. 3.

The figure may be of further uſe, by applying a thin cap, with a hole in it, a quarter of an inch ſquare, exact in the focus of the lens; by which means, when a piece of linen cloth is applied upon the braſs, and viewed through the other end, the threads will appear greatly magnified, ſo that they may be counted, and thereby the quality of the cloth may be aſcertained by calculation. Fig. 4.

M is a flat ſlip of ivory, called a ſlider, with four round holes through it, wherein to place objects between two glaſſes or pieces of Muſcovy talc, as they appear d d d d. Fig. 5.

Eight ſuch ivory ſliders, and one of braſs, are uſually ſold with this microſcope; ſome with objects placed in them, and others empty, for viewing any thing that may offer: but whoever pleaſes to make a large collection of objects, may have as many as he deſires.

The

The braſs ſlider is to confine any ſmall object, that it may be viewed without cruſhing or deſtroying it.

Fig. 6. N is a forceps or pair of plyers, for the taking up inſects or other objects, and adjuſting them to the glaſſes.

Fig. 7. O is a little hair-bruſh, or pencil, wherewith to wipe any duſt from off the glaſſes, or to take up any ſmall drop of liquid one would examine, and put it upon the talcs or iſinglaſs.

Fig. 8. P is a tube of glaſs, contrived to confine living objects, ſuch as frogs, fiſhes, &c. in order to diſcover the blood, as it ſtreams along the veins and arteries.

All theſe particulars are contained in a little neat box, very convenient for carrying in the pocket.

When an object is to be viewed, thruſt the ivory ſlider, in which the ſaid object is placed, between the Fig. 1. two flat braſs plates E E; obſerving always to put that ſide of the ſlider where the braſs rings are, fartheſt from your eye. Then ſcrew on the magnifying glaſs you intend to uſe, at the end of the inſtrument G; and looking through it againſt the light, turn the long ſcrew C C, till your object be brought to fit your eye; which you will know by its appearing then perfectly diſtinct and clear. 'Tis beſt to look at it firſt through a magnifier that can ſhew the whole thereof at once, and afterwards to inſpect the ſeveral parts more particularly with one of the greateſt magnifiers; for thus you will gain a true idea of the whole, and of all its parts. And though the greateſt magnifiers can ſhew but a minute portion of any object at once, ſuch as the claw of a flea, the horn of a louſe, or the like, yet, by gently

gently moving the ſlider that contains your object, the eye will gradually overlook it all; and if any part ſhould be out of diſtance, the ſcrew C C will eaſily bring it to the true focus.

As objects muſt be brought very near the glaſſes when the greateſt magnifiers are uſed, be particularly careful not to ſcratch them as you move it in or out. A few turns of the ſcrew C C will eaſily prevent this miſchief, by giving them room enough.

You may change the objects in your ſliders for what others you think proper, by taking out the braſs ring with the point of a penknife; the talc will then fall out, if you but turn the ſliders; and after putting what you pleaſe between them, by replacing the braſs rings, you will faſten them as they were before. 'Tis proper to have ſome ſliders furniſhed with talcs, but without any objects between them, to be always in readineſs for the examination of fluids, ſalts, ſands, powders, the farina of flowers, or any other caſual objects of ſuch ſort as need only be applied to the outſide of the talc.

The circulation of the blood may eaſieſt be ſeen in the tails and fins of fiſhes, in the fine membranes between a frog's toes, or beſt of all, in the tail of a water-newt. If your object be a ſmall fiſh, place it within the tube, and ſpread its tail or fin againſt the ſide thereof: if a frog, chuſe ſuch an one as can but juſt be got into your tube, and with a pen or ſtick expand the tranſparent membrane between the toes of the frog's hind foot as wide as you are able. When your object is ſo adjuſted, that no part thereof can intercept the

the light from the place you intend to view, unſcrew the long ſcrew C C, and thruſt your tube into the arched cavity, quite through the body of the microſcope; then ſcrew it to the true focal diſtance, and you will ſee the blood paſſing along its veſſels with a rapid motion, and in a moſt ſurpriſing manner.

Make uſe of the third or fourth magnifier for frogs or fiſhes; but for the tails of water-newts, the fifth or ſixth will do, becauſe the globules of their blood are twice as large as thoſe of frogs or fiſh. The firſt or ſecond magnifier cannot well be employed to this purpoſe; for the thickneſs of the tube wherein the object lies, will ſcarce admit its being brought ſo near as the focal diſtance of the magnifier.

A Pocket Microſcope, with a Reflecting Speculum.

Fig. 9. A is a ſcroll of braſs, fixed upright on a round pedeſtal of wood B, ſo as to ſtand perfectly firm and ſteady.

C is a braſs ſcrew, that paſſes through a hole in the upper limb of the ſcroll, into the ſide of the microſcope D, and ſcrews it faſt to the ſaid ſcroll.

E a concave looking-glaſs or ſpeculum, ſet in a box of braſs, which hangs in the arch G, by two ſmall ſcrews f f, that ſcrew into the oppoſite ſides thereof.

At

At the bottom of the ſaid arch is a pin of the ſame metal, exactly fitted to a hole h, in the wooden pedeſtal, made for the reception of the ſaid pin.

As the arch turns to this pin, and the ſpeculum turns on the ends of the arch, it may, by this twofold motion, be eaſily adjuſted, in ſuch a manner as to reflect the light of the ſky, the ſun, or a candle, directly upwards, through the microſcope that is fixed perpendicularly over it; and by ſo doing, may be made to anſwer almoſt all the ends of the large double reflecting microſcope.

The body of the microſcope may alſo be fixed horizontally, and objects may be viewed in that poſition by any light you chooſe: which is an advantage the reflecting microſcope has not.

It may alſo be rendered farther uſeful, by means of a ſlip of glaſs, one end of which being thruſt between the plates where the ſliders go, and the other extending to ſome diſtance, ſuch objects may be placed thereon as cannot be applied to the ſliders: and then, having a limb of braſs that may be faſtened to the body of the microſcope, and extend over the projecting glaſs a hollow ring, wherein to ſcrew the magnifiers, all ſorts of ſubjects may be examined with great conveniency, if a hole be made in the pedeſtal to place the ſpeculum exactly underneath, and thereby throw up the rays of light as in the next figure.

The pocket-microſcope thus fixed, is, if I may preſume to judge, as eaſy and pleaſant in its uſe, and as fit for the moſt curious examination of the animalcules

and ſalts in fluids, of the farinæ in vegetables, of the circulations in ſmall creatures: in ſhort, it is likely to make as conſiderable diſcoveries in objects that have ſome degree of tranſparency, as any microſcopes I have ever ſeen or heard of.

Another ſingle Microſcope on a Foot or Stand.

THE ſingle microſcopes, hitherto deſcribed, have been contrived in many different forms; which on ſome occaſions are very neceſſary and convenient. I have here given the form or ſtructure of one which I think, in ſome caſes, preferable to any I have ſeen.

This is the general form of the inſtrument in which A B is the baſis or foot.

Fig. 10. C D I is the ſtem, of which the lower part C is in the form of a pillar; and the upper part D has four plain ſides.

E F are two ſquare ſockets of braſs, moveable up and down together upon the ſquare part of the ſtem, being connected by a common ſcrew; but this motion is checked by the conſtant preſſure of a ſpring.

G is a ſcrew, by which the part E is fixed to the ſtem.

H is an adjuſting ſcrew, by which the part F is gradually moved up and down: and thereby K L, the ſtage on which the objects are placed, has M N the ſlider, with its objects, duly adjuſted to the focus of the magnifiers.

L is

L is a joint by which the ſtage is capable of an horizontal motion, to ſhew any part of the object without moving the ſlider.

O P is a circular piece of braſs conſiſting of two plates, between which are placed ſix ſmall lenſes or magnifiers in a circle near the extreme part, and is moveable on a ſcrew, in its center, which goes into I Q, a piece of braſs fixed very firmly on the top of the ſtem; upon this is Q a circular piece of braſs ſoldered on, with a hole in the center, under which the circle of glaſſes below paſſes; and, conſequently, any one of the lenſes being brought to the center of this hole, will be exactly over the center of the hole in the ſtage, and ſhew the objects when adjuſted to the focus of the ſaid lens.

R is the ſpeculum that reflects the light through the microſcope.

A Megalaſcope, for viewing large Objects.

THIS is an optical inſtrument that may be properly called a megalaſcope for the hand, becauſe it is adapted for viewing all the larger ſort of ſmall objects; ſuch as inſects, flowers, minerals, linen, &c. to a very great advantage; as with three glaſſes only it has ſeven different magnifying powers.

A B is the caſe of braſs, ſilver, &c. Fig. 11.

D, E, F, three ſeveral lenſes with different magnifying powers, which are all contained in the ſaid caſe, and turned out at pleaſure.

H the handle.

The three glaſſes ſingly, afford three magnifying powers, and by combining two and two, we make three more; for D with E makes one, D with F another, and E with F a third; which, with the three ſingly, make ſix: and laſtly, all three combined together make another, ſo that, upon the whole, there are ſeven powers of magnifying with three glaſſes only.

Of Double or Compound Microſcopes.

Fig. 12. The Double or Compound Microſcope, conſiſts of an object-glaſs c d, and an eye-glaſs e f. The ſmall object a b is placed at a little greater diſtance from the glaſs c d than its principal focus, ſo that the pencils of rays flowing from the different points of the object, and paſſing through the glaſs, may be made to converge and unite in as many points between g and h, where the image of the object will be formed: which image is viewed by the eye through the eye-glaſs e f. For the eye-glaſs being ſo placed, that the image g h may be in its focus, and the eye much about the ſame diſtance on the other ſide, the rays of each pencil will be parallel after going out of the eye-glaſs, as at e and f, till they come to the eye at k, where they will begin to converge by the refractive powers of the humours; and after having croſſed each other in the pupil, and paſſed through the chryſtalline and vitreous humours, they will be collected into points on the retina, and form the large inverted image A B thereon.

The

The magnifying power of this microſcope is as follows: Suppoſe the image g h to be ſix times the diſtance of the object a b from the object-glaſs c d; then will the image be ſix times the length of the object: but ſince the image could not be ſeen diſtinctly by the bare eye at a leſs diſtance than ſix inches, if it be viewed by an eye-glaſs e f, of one inch focus, it will thereby be brought ſix times nearer the eye; and conſequently viewed under an angle ſix times as large as before; ſo that it will be again magnified ſix times; that is, ſix times by the object-glaſs, and ſix times by the eye-glaſs; which multiplied into one another, makes thirty-ſix times; and ſo much is the object magnified in diameter more than what it appears to the bare eye; and conſequently thirty-ſix times thirty-ſix, or one thouſand two hundred and ninety-ſix times in ſurface.

But becauſe the extent or field of view is very ſmall in this microſcope, there are generally two eye-glaſſes placed ſometimes cloſe together, and ſometimes an inch aſunder; by which means, although the object appears leſs magnified, yet the viſible area is much enlarged by the interpoſition of a ſecond eye-glaſs; and conſequently a much pleaſanter view is obtained.

The Deſcription and Uſe of a Compound Microſcope,

Is the form of a compound microſcope for the pocket. Fig. 13.

A Q is the body or internal part which is moveable up and down in C D, an external caſe of wood, braſs, or ſilver.

E, one

E, one of the three pillars which ſupport the inſtrument.

F, a plate fixed (horizontally) to the legs, uſually called the ſtage.

G, a hole in the central part, in which glaſs, and other parts of the apparatus are placed, with objects to be viewed.

H, an illuminating or reflecting ſpeculum.

I, the foot of the inſtrument.

K, is a pipe to which is ſcrewed

Q, a braſs button or caſe to hold the magnifier.

In this compound microſcope there are generally three (ſometimes four) glaſſes employed to produce the effect, viz. 1. The magnifying lens at Q, which makes a large image in the upper part of the ſmall object below. 2. A large lens at B, called the body-glaſs, which is the cauſe of a larger field of view. 3. An eye-glaſs at A, by which we view the enlarged image of the object in its focus.

The Method of computing the Magnifying Power of Single and Double Microſcopes.

THE magnifying power in all optical inſtruments depends upon this one principle, that every object is apparently greater or leſs in proportion as it is nearer to or farther from the eye; becauſe the nearer it is, the

the larger is the viſual angle under which it appears, *& vice verſa.*

But the eye is ſo formed as to admit of diſtinct viſion by ſuch rays only as are nearly parallel; and therefore every object muſt be removed to ſuch a diſtance from the eye that the rays of light iſſuing from every point thereof, may fall upon the eye with ſmall divergency, or nearly parallel; which diſtance is in different eyes from ſix to eight inches, as any one may find by trial.

Now, ſince a convex glaſs convenes parallel rays to a point or focus; therefore, on the contrary, if an object be placed in the focus of ſuch a lens, the rays proceeding from each point will be refracted parallel to the eye, and thereby produce diſtinct viſion of that object in its focus.

Hence then it follows, that if a b be a very ſmall object in the focus of the glaſs c, whoſe focal diſtance is one inch, the eye applied to the lens C will have the diſtinct viſion thereof; and this being at a diſtance ſix, ſeven, or eight times nearer than the eye alone could clearly ſee it, it muſt appear ſo many times larger than to the naked eye; and therefore we properly ſay, it is magnified to ſuch eyes, ſix, ſeven, or eight times in length and breadth. Fig. 14.

But all ſurfaces are magnified in proportion to the ſquares of their lengths or ſides; therefore the ſurfaces of objects are magnified thirty-ſix, forty-nine, or ſixty-four times, by a lens of one inch focal diſtance.

Alſo the bulk or magnitude of the whole body, will be

be magnified in proportion to the cubes of the ſides or length; and therefore all ſolid bodies will, by ſuch a lens, be magnified two hundred and ſixteen, three hundred and forty-three, or five hundred and twelve times, to ſuch eyes reſpectively.

If the lens C were but of half an inch focal diſtance, the lengths of the objects would be magnified twice as much: the ſurfaces four times, and the magnitude or bulk, eight times as much as before.

If the focal diſtance of the lens C be a quarter of an inch, then the lengths aremagnified four times as much, viz. twenty-four, twenty-eight, or thirty-two times; the ſurfaces ſixteen times as much, or 576 times more than to the naked eye at ſix inches diſtance; and ſolid bodies are magnified ſixty-four times more than by the lens of a whole inch focal diſtance.

Once more: Suppoſe the lens ſo ſmall that its focal diſtance is but 1-tenth of an inch, then the length of an object is magnified ſixty, ſeventy, or eighty times; the ſurface 3,600, 3,900, or 6,400 times; and the ſolidity or whole bulk 216,000, 343,000, or 512,000 times, or ſo much larger do the bodies of mites, or their eggs, appear than to the naked eye at ſix, ſeven, or eight inches diſtance.

After the ſame manner you may compute the magnifying power of lenſes of 1-twentieth, 1-thirtieth, 1-fortieth and even 1-fiftieth part of an inch focal diſtance, which may be made if required; but they are with difficulty uſed. By a lens 1-fiftieth of an inch, the

the length is magnified 300 times; and the ſurface 90,000 times; and the ſolidity 27,000,002 times.

But theſe enormous powers of magnifying are much better effected in compound microſcopes; and be that in what degree you pleaſe, it is thus eaſily eſtimated. Let C be the object lens in the cell Q, Fig. 13 of the compound microſcope; if then a ſmall object, a b, be placed on the ſtage at G, a little more than the focal diſtance, there will be formed by the ſaid lens C, a large image S T, in the upper part of the microſcope; and this image is viewed through the glaſs G H in its focus below at O. Fig. 13.

Now it is eaſy to underſtand that the image S T is as much larger than the object a b, as the diſtance C A exceeds the diſtance C a from the lens. Suppoſe the image S T ſix times larger than the object a b; then if it be viewed by a lens G H of one inch focal diſtance, the image S T will appear magnified ſix times at leaſt, and therefore the object a b will be magnified ſix times ſix, or 36 times in length; and 36 times 36, or 1,296 times in ſurface; and 36 times 1,296, or 46,656 times in the bulk of ſolidity. And yet with theſe great powers of magnifying, the lens C may not be of leſs than half an inch focal diſtance, in the leaſt ſort of compound pocket microſcopes.

But with a ſingle eye-glaſs G H, we have too ſmall a field of view, therefore we uſe two, viz. A B and D E; the firſt contracts the image S T into another, I M, which is leſs; and this is viewed by the eye-glaſs D E. Now both theſe glaſſes may have a magnifying power equal to that of a given ſingle glaſs G H, by this rule: Let their diſtance be equal to the difference

of their focal lengths, and their magnifying power will be equal to that of a lens whoſe focal diſtance is half that of the greater A B.

For example: Suppoſe the focal length of A B to be two inches 1-half, and that of D E one inch; then if their diſtance be one inch 1-half, their joint magnifying power will be equal to that of a ſingle lens G H, whoſe focal diſtance is one 1-fourth equal half that of A B. By the two eye-glaſſes the rays are converged to the eye at the compound focus F, much leſs affected by the errors ariſing from the aberration of rays, both from their different refrangibility and the figure of the glaſſes.

The Solar, or Camera Obſcura Microſcope.

THIS microſcope depends on the ſun-ſhine, and muſt be made uſe of in a darkened chamber, as its name implies.

It is compoſed of a tube, a looking-glaſs, a convex lens, and Wilſon's ſingle pocket microſcope, before deſcribed.

The ſun's rays being directed by the looking-glaſs through the tube upon the object, the image or picture of the object is thrown, diſtinctly and beautifully, upon a ſcreen of white paper, or a white linen ſheet, placed at ſome diſtance to receive the ſame; and may be magnified to a ſize beyond the imagination of thoſe who have not ſeen it; for the farther off the ſcreen is removed, the larger will the object appear; inſomuch, that a louſe may be magnified to the length of five or

ſix

v.

A
B

A
a
L
c
B

ſix feet, or even a great deal more: but it is indeed more diſtinct when not enlarged to above half that ſize.

The apparatus for this purpoſe, as repreſented in the plate annexed, is as follows: Plate XV.

A, a ſquare wooden frame, through which two long ſcrews paſs, and aſſiſted by a couple of nuts (1. 1.) faſten it firmly to a window-ſhutter, wherein a hole is made for its reception; the two nuts being let into the ſhutter, and made faſt thereto. Fig. 1.

A circular hole is made in the middle of this frame, to receive a piece of wood of a circular figure B, whoſe edge that projects a little beyond the frame, compoſes a ſhallow groove 2, wherein runs a cat-gut 3; which by twiſting round, and then croſſing over a braſs pulley 4, (the handle whereof 5, paſſes through the frame) affords an eaſy motion for turning round the circular piece of wood B, with all the parts thereto affixed.

C is a braſs tube covered with ſeal-ſkin, which ſcrewing into the middle of the circular piece of wood, becomes a caſe for the uncovered braſs tube D, to be drawn backwards or forwards in.

E, a ſmaller tube of about one inch in length, ſcrewed to the end of the larger tube D.

F is another ſhort braſs tube, made to ſlide over the above-deſcribed tube E. To the end hereof the microſcope muſt be ſcrewed when we come to uſe it.

5, A convex lens, whoſe focus is about twelve inches; deſigned to collect the ſun's rays, and throw them more ſtrongly upon the object.

G, a looking-glaſs of an oblong figure, ſet in a wooden frame, faſtened by hinges to the circular piece of wood B, and turning about therewith, by means of the above-mentioned cat-gut.

H, a jointed wire, partly braſs and partly iron; the braſs part whereof, which is flat 6, being faſtened to the looking-glaſs, and the iron part, which is round 7, paſſing through the wooden frame, enable the obſerver (by putting it backwards or forwards) to elevate or decline the glaſs according to the ſun's altitude.

1, A braſs ring at the end of the jointed wire, whereby to manage it with greater eaſe.

N. B. The extremities of the cat-gut are faſtened to a braſs pin; by turning of which it may be braced up, if at any time it becomes too ſlack. This pin lying behind, could not be ſhown in the picture.

When this microſcope is employed, the room muſt be rendered as dark as poſſible; for on the darkneſs of the room and the brightneſs of the ſun-ſhine, depend the ſharpneſs and perfection of your image. Then putting the looking-glaſs G through the hole in your window-ſhutter, faſten the ſquare frame A to the ſaid ſhutter by its two ſcrews and nuts, 1. 1.

This

This done, adjuſt your looking-glaſs to the elevation and ſituation of the ſun, by means of the jointed wire H, together with the cat-gut pulley 3, 4; for the firſt of theſe raiſing or lowering the glaſs, and the other reclining it to either ſide, there reſults a twofold motion, which may eaſily be ſo managed as to bring the glaſs to a right poſition; that is, to make it reflect the ſun's rays directly through the lens 5, upon the paper ſcreen, and form thereon a ſpot of light exactly round.

Though obtaining a perfect circular ſpot of light upon the ſcreen before you apply the microſcope, is a certain proof that your looking-glaſs is adjuſted right, yet that proof muſt not always be expected; for the ſun is ſo low in winter, that if it ſhines in a direct line againſt the window, it cannot then afford a ſpot of light exactly round. But if it be on either ſide of you, a round ſpot may be obtained, even in December.

As ſoon as this appears, ſcrew the tube C into the braſs collar provided for it in the middle of your woodwork, taking care not to alter your looking-glaſs; then ſcrewing the magnifier you chuſe to employ to the end of your microſcope, in the uſual manner, take away the lens at the other end thereof, and place a ſlider, containing the object to be examined, between the thin braſs plates, as in the other ways of uſing the microſcope.

Things being thus prepared, ſcrew the body of your microſcope to the ſhort braſs tube F, which ſlip over the ſmall end E of the tube D, and pull out the ſaid tube D leſs or more as your object is capable of enduring the ſun's heat. Dead objects may be brought within about an inch of the focus of the convex lens 5; but

but the diſtance muſt be ſhortened for living creatures or they will ſoon be killed.

If the light falls not exactly right, you may eaſily by a gentle motion of the jointed wire and pulley, direct it through the axis of the microſcopic lens.

The ſhort tube F, which your microſcope is ſcrewed to, enables you, by ſliding it backwards or forwards on the other tube E, to bring your object to their true focal diſtance; which will be known by the ſharpneſs and clearneſs of their appearance; they may alſo be turned round by the ſame means, without being in the leaſt diſordered.

The magnifiers moſt uſeful in the ſolar microſcope are, in general, the fourth, fifth, or ſixth.

Mention having been often made of a ſcreen to throw the images of objects on, it is proper to inform the reader, that ſuch a ſcreen is uſually compoſed of a ſheet of the largeſt elephant paper, ſtrained on a frame, which ſlides up or down, or turns about at pleaſure on a round wooden pillar, in the manner of ſome fire-ſcreens. Larger ſcreens are likewiſe made ſometimes, with ſeveral ſheets of the ſame paper paſted together on cloth, and let down from the ceiling with a roller, like a large map.

This microſcope is the moſt entertaining of any; and, perhaps, the moſt capable of making diſcoveries in objects that are not too opaque, as it ſhews them much larger than can be done any other way. There are alſo ſeveral conveniences attending it, which no other

microſcope

microſcope can have; for the weakeſt eyes may uſe it without the leaſt ſtraining or fatigue: numbers of people may view any object together, at the ſame time; and, by pointing to the particular parts thereof, and diſcourſing on what lies before them, may be able better to underſtand one another, and more likely to find out the truth, than when, in other microſcopes, they muſt peep one after another, and perhaps ſee the object neither in the ſame light, nor the ſame poſition. Such too as have no ſkill in drawing, may, by this contrivance, eaſily ſketch out the exact figure of any object they have a mind to preſerve a figure of; ſince they need only faſten a paper upon the ſcreen, and trace it out thereon, either with a pen or pencil, as it appears before them.

It is worth their while, who are deſirous to take many draughts in this way, to get a frame, wherein a ſheet of paper may be put in or taken out at pleaſure; for if the paper be ſingle, the image of an object will be ſeen as plainly almoſt on the back as on the other ſide; and by ſtanding behind the ſcreen, the ſhade of the hand will not obſtruct the light in drawing, as it muſt in ſome degree when one ſtands before it.

I muſt obſerve that Dr. Liberkhun's ſolar microſcope had no looking-glaſs belonging to it, and therefore was of uſe a few hours only in a day, when the tube could be placed directly againſt the body of the ſun, and even then not without a good deal of trouble; but by this lucky contrivance of a looking-glaſs, the ſun's rays may be reflected through the tube, whatever its height or ſituation be, provided it ſhines at all upon

upon the window, and that too with much eaſe and advantage.

Of the Nature and Uſe of the Micrometer in viewing ſmall Objects.

MANY and expenſive have been the contrivances for meaſuring ſmall objects, in all their dimenſions, by that inſtrument called a Micrometer. I ſhall refer the reader to the ſeveral writers on optics for an account of them, and ſhall here only propoſe one other method, which will come eaſy, and be very ready in practice; the conſtruction of which is a ſufficient explanation of its reaſon and uſe.

The new micrometer is nothing more than a ſtage (on which the objects are placed) moveable by a fine ſcrew, which has a hand or ſmall index paſſing over the diviſions of a graduated circle. A fine threaded ſcrew is the eſſential part in all micrometers, of the beſt or moſt perfect kind. This ſcrew was formerly placed in the focus of the eye-glaſs D E, juſt where the image I M is formed: but I found this method of applying it gave ſome trouble in underſtanding and computing the dimenſions taken by it; and therefore I have here applied to the ſtage, or rather to the object itſelf; which being attended with no difficulty, will, I preſume, render the uſe of it more general and pleaſant.

The upper part of the microſcope which contains the glaſs D E, has a fine wire in its focus, and to it any part of the image I M may be applied; or the wire applied to any part of the image, by a proper conſtruction of

of the upper part of the microſcope for that purpoſe. The object being then placed in a proper manner on the ſtage, the ſcrew is to be turned till the image of the object has paſſed its whole length or breadth under the wire, and then the quantity of its dimenſion will be known. Thus, for example:

The number of threads on the ſcrew in one inch is fifty, and the number of diviſions on the circular plate is twenty. Therefore one thread, or one turn of the ſcrew, meaſures one fiftieth part of an inch; and one diviſion of the plate is one twentieth of one fiftieth, that is one thouſandth part of an inch. So that ſuch a micrometer will very exactly meaſure any ſmall object, or its ſmaller parts to the thouſandth part of an inch.

Suppoſe the ſubject were a mite, and it were required to meaſure the length thereof; then I place it in a ſlider, and that ſlider on a ſtage in ſuch a manner, that the mite may move length-wiſe in the direction of a ſcrew; then I move or ſet the wire at right angles thereto, and ſo as to touch the image of the mite at one end, very exactly. This done, I turn the wire till the image has paſſed its whole length under the wire; and having counted the turns, I find them four, and fourteen diviſions of another; the four turns are 4-fiftieths or 80-thouſandths, and the fourteen diviſions are 14 thouſandths; ſo that the whole length of the mite is 94-thouſandths part of an inch, which is almoſt 1-tenth part of an inch.

Again, for a ſecond example: ſuppoſe you meaſure the length of the egg of a mite, and find one turn of the ſcrew, and three diviſions on the plate, carry it completely

under the wire; then one revolution of the ſcrew is 1-fiftieth or 20-thouſandth, and three diviſions are 3-thouſandth, ſo the whole length of the egg is equal to 23-thouſandth of an inch; that is, almoſt one forty-fourth part of an inch; or forty-four ſuch eggs of a mite will, if laid contiguouſly in a right line, be nearly equal to one inch in length.

I may here add, that the micrometer may be eaſily applied to the ſolar microſcope; for let a fine ſtraight line be drawn on the ſcreen, and the end or ſide of the image be placed to touch it, then by turning the ſcrew, it will thereby be meaſured in thouſandth parts of an inch.

How great the pleaſure ariſing to the curious naturaliſts muſt be in the uſe of the micrometer, meaſuring the ſmalleſt objects, may be better conceived than expreſſed, when by this means he acquires an idea of the wonderful diſproportion there is between the magnitudes or dimenſions of the ſmalleſt and largeſt objects of the ſame ſpecies; as between the ſmalleſt of the finny fry and the largeſt whale; an animalcule in vinegar and a rattleſnake thirty or forty feet long. And that the reader may have a clear perception of ſuch a ſurpriſing contraſt in the works of nature, I ſhall here give him a calculation of the comparative magnitude of the egg of a mite, and that of an oſtrich.

Suppoſe the length of an oſtrich's egg to be five inches (ſome are larger); let the length of the egg of a mite be one fiftieth of an inch, and ſome are leſs than that; then the lengths of theſe two eggs will be to each other as five to one fiftieth, or two hundred and fifty to one; then as they are ſimilar bodies, their magnitudes will be as the cubes of theſe

theſe numbers, viz. as 15625000 to one: that is in words, one egg of an oſtrich is equal to fifteen million ſix hundred and twenty-five thouſand eggs of a mite. And there is great reaſon to believe, that there are eggs of other animalcules in a ſtill greater degree leſs than thoſe of a mite. Indeed, the greateſt ſtretch of the human mind is infinitely inſufficient to explore the amazing and inconceiveable gradations of miniature in every part of nature, even at their very commencement; and nothing but the all-piercing eye of boundleſs intelligence can ſee through a ſeries of ſuch infinitely decreaſing progreſſions.

A Diagram of the Solar Microſcope.

LET A B be a ſection of the window ſhutter of a dark room, C D of the frame containing a ſcioptric ball E F; in the forepart whereof is ſcrewed the tube G I K H, at one end of which is a lens G H, which, by converging the ſun-beams into a narrow compaſs, does ſtrongly enlighten the ſmall object a b, placed on a ſlip of glaſs, or otherwiſe, in the part of the tube N Q, where a ſlit is made on each ſide for that purpoſe. Within this tube there ſlides another, L m r M, which contains a ſmall magnifying lens m r. Plate XIV. Fig. 2.

By moving the exterior tube I G H K one way, and the other, the glaſs G H will be brought to receive the rays of the ſun directly, and will therefore moſt intenſely illuminate the object a b. The other tube L M, being ſlid backwards and forwards, will adjuſt the diſtance of the ſmall lens m r, ſo that the image of the object a b ſhall be made very diſtinct, on the oppoſite ſide of the room at O P; and

the magnitude of the image will be to that of the object, as the diſtance from the lens m r is to the diſtance of the object from it; as is evident from the figure.

Of TELESCOPES.

BEFORE we enter upon the deſcription of teleſcopes, it will be proper to ſhew how the rays of light are affected by paſſing through concave glaſſes, and alſo by falling upon concave mirrours.

Fig. 3. When parallel rays, as a b c d e f g h, paſs directly through a glaſs A B, which is equally concave on both ſides, they will diverge after paſſing through the glaſs, as if they had come from a radiant point C, in the center of the glaſs's concavity; which point is called the negative or virtual focus of the glaſs. Thus the ray a, after paſſing through the glaſs A B, will go on in the direction k l, as if it had proceded from the point C, and no glaſs being in the way. The ray b will go on in the direction m n; the ray c in the direction o p, &c. The ray C, that falls directly upon the middle of the glaſs, ſuffers no refraction in paſſing through it; but goes on in the ſame rectilineal direction, as if no glaſs had been in its way.

If the glaſs had been concave only on one ſide, and the other ſide quite plane, the rays would have diverged, after paſſing through it, as if they had come from a radiant point at double the diſtance of C from the glaſs; that is, as if the radiant had been at the diſtance of a whole diameter of the glaſs's concavity.

If

If rays come more converging to ſuch a glaſs than parallel rays diverge after paſſing through it, they will continue to converge after paſſing through it; but will not meet ſo ſoon as if no glaſs had been in the way; and will incline towards the ſame ſide to which they would have diverged, if they had come parallel to the glaſs. Thus the rays f and h going in a converging ſtate towards the edge of the glaſs at B, and converging more in their way to it than the parallel rays diverge after paſſing through it, they will go on converging after they paſs through it, though in a leſs degree than they did before, and will meet at l: but if no glaſs had been in their way, they would have met at i.

When the parallel rays, as d f a, C m b e l c, fall upon a concave mirrour A B (which is not tranſparent, but has only the ſurface A b B of a clear poliſh) they will be reflected back from that mirrour, and meet in a point m, at half the diſtance of the ſurface of the mirrour from C, the center of its concavity: for they will be reflected at as great an angle from the perpendicular to the ſurface of the mirrour as they fell upon it, with regard to that perpendicular; but on the other ſide thereof. Thus, let C be the center of concavity of the mirrour A b B, and let the parallel rays d f a, C m b, and e l c, fall upon it at the points a b and c. Draw the lines C i a, C m b, and C h c from the center C to theſe points; and all theſe lines will be perpendicular to the ſurface of the mirrour, becauſe they proceed thereto like ſo many radii or ſpokes from its center. Make the angle C A h equal to the angle d a C, and draw the line a m n, which will be the direction of the ray d f a, after it is reflected from the point of the mirrour: ſo that the angle of incidence d a C, is equal Fig. 4.

to

to the angle of reflection C a h; the rays making equal angles with the perpendicular C i a on its oppoſite ſides.

Draw alſo the perpendicular C h c to the point c, where the ray e l c touches the mirrour; and, having made the angle C c i, equal to the angle C c e, draw the line c m i, which will be the courſe of the ray e l c, after it is reflected from the mirrour.

The ray C m b paſſes through the center of concavity of the mirrour, and falls upon it at b, the perpendicular to it; and is therefore reflected back from it in the ſame line b m C.

All theſe reflected rays meet in the point m; and in that point the image of the body which emits the parallel rays d a, C d, and e c will be formed: which point is diſtant from the mirrour equal to half the radius b m C of its concavity.

The rays which proceed from any celeſtial object, may be eſteemed parallel at the earth; and therefore, the images of that object will be formed at m, when the reflecting ſurface of the concave mirrour is turned directly towards the object. Hence the focus of the parallel rays is not in the center of the mirrour's concavity, but half way between the mirrour and that center.

The rays which proceed from any remote terreſtrial object, are nearly parallel at the mirrour: not ſtrictly ſo but come diverging to it in ſeparate pencils, or, as it were, bundles of rays, from each point of the ſide of the object next the mirrour; therefore they will not be converged to a point

a point at the diſtance of half the radius of the mirrour's concavity from its reflecting ſurface; but in ſeparate points at a little greater diſtance from the mirrour. And the nearer the object is to the mirrour, the farther theſe points will be from it; and an inverted image of the object will be formed in them, which will ſeem to hang pendant in the air: and will be ſeen by an eye placed beyond it (with regard to the mirrour) in all reſpects like the object, and as diſtinct as the object itſelf.

Let A c B be the reflecting ſurface of a mirrour, whoſe center of concavity is at C; and let the upright object D E be placed beyond the center C, and ſend out a conical pencil of diverging rays from its upper extremity D, to every point of the concave ſurface of the mirrour A c B. But to avoid confuſion, we only draw three rays of that pencil; as D A, D c, D B. Fig. 5.

From the center of concavity C, draw the three right lines C A, C c, C B, touching the mirrour in the ſame points where the aforeſaid touch it, and all theſe lines will be perpendicular to the ſurface of the mirrour. Make the angle C A d equal to the angle D A C, and draw the right line A d for the courſe of the reflected ray D A: make the angle C c d equal to the angle D c C, and draw the right line c d for the courſe of the reflected ray D d: make alſo the angle C B d equal to the angle D B C, and draw the right light line B d for the courſe of the reflected ray D B. All theſe reflected rays will meet in point d, where they will form the extremity d of the inverted image e d, ſimilar to the extremity D of the upright object D E.

If

If the pencils of rays E f, E g, E h, be alſo continued to the mirrour, and their angles of reflection from it be made equal to their angles of incidence upon it, as in the former pencil from D, they will all meet at the point e by reflection, and form the extremity e of the image e d, ſimilar to the extremity E of the object D E.

As each intermediate point of the object between D and E, ſends out a pencil of rays in like manner to every part of the mirrour, the rays of each pencil will be reflected back from it, and meet in all the intermediate points between the extremities e and d of the image; and ſo the whole image will be formed not at i, half the diſtance of the mirrour from its center of concavity C, but at a greater diſtance between i and the object D E; and the image will be inverted with reſpect to the object.

This being well underſtood, the reader will eaſily ſee how the image is formed by the large concave mirrour of the reflecting teleſcope, when he comes to the deſcription of that inſtrument.

When the object is more remote from the mirrour than its center of concavity C, the image will be leſs than the object, and between the object and the mirrour; when the object is nearer than the center of concavity, the image will be more remote and bigger than the object: thus, if D E be the object, e d will be its image; for as the object recedes from the mirrour, the image approaches nearer to it; and as the object approaches nearer to the mirrour, the image recedes farther from it; on account of the leſſer or greater divergency of the pencils of rays which proceed from the object; for the leſs they diverge, the

ſooner

ſooner they are converged to points by reflection; and the more they diverge, the farther they muſt be reflected before they meet.

If the radius of the mirrour's concavity and the diſtance of the object from it be known, the diſtance of the image from the mirrour is found by this rule: Divide the product of the diſtance and radius by double the diſtance made leſs by the radius, and the quotient is the diſtance required.

If the object be in the center of the mirrour's concavity, the image and object will be coincident, and equal in bulk.

If a man places himſelf directly before a large concave mirrour, but farther from it than its center of concavity, he will ſee an inverted image of himſelf in the air, between him and the mirrour, of a leſs ſize than himſelf. And if he holds out his hand towards the mirrour, the hand of the image will come out towards his hand, and coincide with it, of an equal bulk, when his hand is in the center of concavity; and he will imagine he may ſhake hands with his image. If he reaches his hand farther, the hand of the image will paſs by his hand, and come between his hand and his body: and if he moves his hand towards either ſide, the hand of the image will move towards the other: ſo that whatever way the object moves, the image will move the contrary way.

All the while a bye-ſtander will ſee nothing of the image, becauſe none of the reflected rays that form it enter his eyes.

If a fire be made in a large room, and a ſmooth mahogany table be placed at a good diſtance near the wall, before a large concave mirrour, ſo placed that the light of the fire may be reflected from the mirrour to its focus upon the table; if a perſon ſtands by the table, he will ſee nothing upon it but a longiſh beam of light: but if he ſtands at a diſtance towards the fire, not directly between the fire and mirrour, he will ſee an image of the fire upon the table, large and erect. And if another perſon, who knows nothing of this matter before hand, ſhould chance to come into the room, and ſhould look from the fire towards the table, he would be ſtartled at the appearance; for the table would ſeem to be on fire, and by being near the wainſcot, to endanger the whole houſe. In this experiment there ſhould be no light in the room but what proceeds from the fire; and the mirrour ought to be at leaſt fifteen inches in diameter.

If the firſt be darkened by a ſcreen, and a large candle be placed at the back of the ſcreen; a perſon ſtanding by the candle will ſee the appearance of a fine large ſtar, or rather planet, upon the table, as bright as Venus or Jupiter. And if a ſmall wax taper (whoſe flame is much leſs than the flame of a candle) be placed near the candle, a ſatellite to the planet will appear on the table: and if the taper be moved round the candle, the ſatellite will go round the planet.

The Refracting Teleſcope.

IN a refracting teleſcope, the glaſs which is neareſt the object in viewing it, is called the object glaſs; and that which

Plate XVI.
Fig. 1.

PLATE XVI.

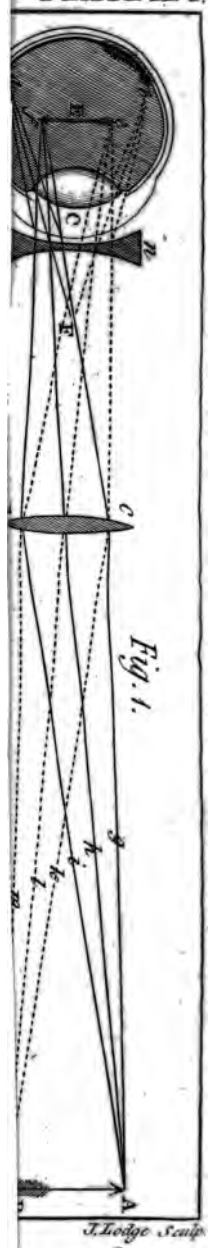

Fig. 1.

which is neareſt the eye is called the eye-glaſs. The object-glaſs muſt be convex, but the eye-glaſs may be either convex or concave: and generally, in looking through a teleſcope, the eye is in the focus of the eye-glaſs, though that is not very material: for the diſtance of the eye, as to diſtinct viſion, is indifferent, provided the rays of the pencils fall upon it parallel: only, the nearer the eye is to the end of the teleſcope, the larger the ſcope or area of the field of view.

Let c d be a convex glaſs fixed in a long tube, and have its focus at E. Then a pencil of rays g h i, flowing from the upper extremity A of the remote object A B, will be ſo refracted by paſſing through the glaſs, as to converge and meet in point f; whilſt the pencil of rays k l m flowing from the lower extremity B, of the ſame object A B, and paſſing through the glaſs, will converge and meet in the point e: and the images of the point A and B, will be formed in the points f and e. And as all the intermediate points of the object between A and B ſend out pencils of rays in the ſame manner, a ſufficient number of theſe pencils will paſs through the object-glaſs c d, and converge to as many intermediate points between e and f; and ſo will form the whole inverted image e E f, of the diſtinct object. But becauſe this image is ſmall, a concave glaſs n o is ſo placed in the end of the tube next the eye, that its virtual focus may be at F. And as the rays of the pencils paſs converging through the concave glaſs, but converge leſs after paſſing through it than before they go on further, as to b and a, before they meet; and the pencils themſelves being made to diverge by paſſing through the concave glaſs, they enter the eye, and form the Plate XVI. Fig. 1.

large picture a b upon the retina, whereon it is magnified under the angle b F a.

But this teleſcope has one inconveniency which renders it unfit for moſt purpoſes; which is, that the pencils of rays being made to diverge by paſſing through the concave glaſs n o, very few of them can enter the pupil of the eye; and therefore the field of view is but very ſmall, as is evident by the figure. For none of the pencils which flow either from the top or bottom of the object A B can enter the pupil of the eye at C, but are all ſtopt by falling upon the iris above and below the pupil: and therefore only the middle part of the object can be ſeen when the teleſcope lies directly towards it, by means of thoſe rays which proceed from the middle of the object. So that to ſee the whole of it, the teleſcope muſt be moved upwards and downwards, unleſs the object be very remote; and then it is never ſeen diſtinctly.

Fig. 2. This inconvenience is remedied by ſubſtituting a convex eye-glaſs, as g h, in place of the concave one; and fixing it ſo in the tube that its focus may be coincident with the focus of the object glaſs c d; as at E. For then the rays of the pencils flowing from the object A B, and paſſing through the object glaſs c d, will meet in its focus, and form the inverted image m E p; and as the image is formed in the focus of the eye-glaſs g h, the rays of each pencil will be parallel, after paſſing through that glaſs; but the pencils themſelves will croſs in its focus, on the other ſide, as at e; and the pupil of the eye being in this focus, the image will be viewed through the glaſs, under the angle g e h; and being at E, it will appear magnified, ſo as to fill the whole ſpace C m e p D.

But,

But, as this teleſcope inverts the image with reſpect to the object, it gives an unpleaſant view of terreſtrial objects; and is only fit for viewing the heavenly bodies, in which we regard not their poſition, becauſe their being inverted does not appear, on account of their being round. But whatever way the object ſeems to move, this teleſcope muſt be moved the contrary way, in order to keep ſight of it; for, ſince the object is inverted, its motion will be ſo too.

The magnifying power of this teleſcope is, as the focal diſtance of the object-glaſs to the focal diſtance of the eye-glaſs. Therefore, if the former be divided by the latter, the quotient will expreſs the magnifying power.

When we ſpeak of magnifying by a teleſcope or microſcope, it is only meant with regard to the diameter, not to the area or ſolidity of the object. But as the inſtrument magnifies the vertical diameter as much as it does the horizontal, it is eaſy to find how much the whole viſible area or ſurface is magnified: for, if the diameters be multiplied into one another, the product will expreſs the magnification of the whole viſible area. Thus, ſuppoſe the focal diſtance of the object-glaſs be ten times as great as the focal diſtance of the eye-glaſs; then, the object will be magnified ten times, both in length and breadth: and ten multiplied by ten produces one hundred; which ſhews that the area of the object will appear one hundred times as big when ſeen through ſuch a teleſcope, as it does to the bare eye.

Hence it appears, that if the focal diſtance of the eye-glaſs were equal to the focal diſtance of the object-glaſs,

glaſs, the magnifying power of the teleſcope would be nothing.

This teleſcope may be made to magnify in any given degree, provided it be of a ſufficient length. For the greater the focal diſtance of the object-glaſs, the leſs may be the focal diſtance of the eye-glaſs, though not directly in proportion. Thus, an object-glaſs of ten feet focal diſtance, will admit of an eye-glaſs whoſe focal diſtance is little more than two inches and a half; which will magnify near forty-eight times; but an object-glaſs of one hundred feet focus, will require an eye-glaſs ſomewhat more than ſix inches; and will therefore magnify almoſt two hundred times.

Fig. 3. A teleſcope for viewing terreſtrial objects, ſhould be ſo conſtructed as to ſhew them in their natural poſture. And this is done by one object-glaſs c d, and three eye-glaſſes e f, g h, i k, ſo placed, that the diſtance between any two, which are neareſt to each other, may be equal to the ſum of their focal diſtances; as in the figure where the focus of the glaſſes c d and e f meet at F, thoſe of the glaſſes e f and g h, meet at l, and of g h and i k, at m; the eye being at n, in or near the focus of the eye-glaſs i k, on the other ſide Then it is plain that theſe pencils of rays which flow from the object A B, and paſs through the object-glaſs c d, will meet and form an inverted image C F D in the focus of that glaſs; and the image being alſo in the focus of the glaſs e f, the rays of the pencils will become parallel, after paſſing through that glaſs, and croſs at l, in the focus of the glaſs e f; from whence they paſs on to the next glaſs g h, and by going through it they are converged to the points in its other focus, where they form

form an erect image E m F, of the object A B; and as this image is alſo in the focus of the eye-glaſs i k, and the eye on the oppoſite ſide of the ſame glaſs; the image is viewed through the eye-glaſs in this teleſcope, in the ſame manner as through the eye-glaſs in the former one; only in a contrary poſition; that is, in the ſame poſition with the object.

The three glaſſes next the eye have all their focal diſtances equal; and the magnifying power of this teleſcope is found the ſame way as that of the laſt above; viz. by dividing the focal diſtance of the object-glaſs c d by the focal diſtance of the eye-glaſs i k, or g h, or e f, ſince all theſe three are equal.

Why the object appears coloured when ſeen through a teleſcope.

When the rays of light are ſeparated by refraction, they become coloured, and if they be united again, they will be a perfect white. But thoſe rays which paſs through a convex glaſs, near its edges, are more unequally refracted than thoſe nearer the middle of the glaſs. And when the rays of any pencil are unequally refracted by the glaſs, they do not all meet again in one and the ſame point, but in ſeparate points; which makes the object indiſtinct, and coloured about the edges. The remedy is, to have a plate with a ſmall round hole in its middle, fixed in the tube at m, parallel to the glaſſes. For the wandering rays about the middle of the glaſſes will be ſtopt by the plate from coming to the eye; and none admitted but thoſe which come through the middle of the glaſs, or at leaſt at a good diſtance from its edges, and paſs through a hole in the middle of the plate. But this circumſcribes the image, and leſſens the field of view, which ſhould be much larger if the plate could be diſpenſed with.

The

The Binocular, or Double Teleſcope.

BESIDES the teleſcopes deſcribed before, there is alſo one called a binocular, or double teleſcope. This is no more than two equal teleſcopes ſet in a frame, parallel to one another; and theſe may be ſet at a proper diſtance from one another, by the help of ſcrews; and that diſtance is to be the ſame as the diſtance of the two pupils of the eyes. When that is adjuſted, a perſon is to look through them both at once; through one with each eye, to any object; which will then be ſeen by both eyes, and appear far brighter then through a ſingle teleſcope.

All teleſcopes in general repreſent all terreſtrial objects to be nearer hand, but not larger; and this nearneſs, vicinity, or ſeeming approach of the object, is as the magnifying power of the teleſcope. Thus looking at a man one hundred yards off, with a teleſcope that magnifies one hundred times; the man will appear to be no bigger, but will ſeem only to be a yard off; and the like of other objects ſituated on the earth.

The magnifying power of a teleſcope will be found if you make two equal circles of paper of an inch diameter or more, and fix one of them upon a wall one hundred or two hundred yards diſtant; and the other at a ſmall diſtance, in a line with the firſt. Then look at the further circle through the teleſcope with one eye, and at the near circle with the other eye naked. Move the near circle (or elſe the teleſcope) back and forward, till the two circles appear equal, or coincide. Then meaſure the two diſtances

tances, from the eye-glaſs of the teleſcope to the two circles; then divide the greater diſtance by the leſſer, and you have the magnifying power of the teleſcope.

To try the Goodneſs of an Object Glaſs.

THERE is no better way for trying the goodneſs of an object glaſs than putting it in a tube, and trying it with ſeveral ſmall eye-glaſſes, by looking at ſeveral diſtant objects, and particularly at the title-page of a book; for that glaſs which repreſents objects the moſt bright and diſtinct, and bears the greateſt aperture, and the ſhorteſt eye-glaſs, without colouring or dimneſs, is the beſt glaſs.

If ſeveral teleſcopes of the ſame length be compared together, thoſe are the beſt with which you can read the ſame print at the greateſt diſtance. And this may be a rule for thoſe that buy teleſcopes, by which they may know how to chooſe the beſt.

There are four principal things in a teleſcope to be conſidered: 1. Magnifying power. 2. Diſtinctneſs. 3. Brightneſs. 4. The viſible angle, or linear view it takes in.

A TABLE of the Focal Distances, Apertures, and Magnifying Powers of Refracting Telescopes.

Foc. obj. glass	aper. obj. glass	Foc. eye glass	mag. power.
Feet.	Inch	Inch	
	.54	.60	20
2	.76	.83	28
3	.94	1.03	34
4	1.08	1.19	40
5	1.22	1.34	44
6	1.32	1.45	49
7	1.43	1.57	52
8	1.53	1.68	56
9	1.62	1.78	60
10	1.71	1.88	64
13	1.95	2.14	73
15	2.09	2.30	78
20	2.42	2.66	90
25	2.70	2.97	101
30	2.96	3.25	110
35	3.20	3.52	119
40	3.41	3.75	128
45	3.62	3.98	135
50	3.82	4.20	143
55	4.00	4.40	150
60	4.18	4.60	156
70	5.52	4.97	169
80	4.83	5.31	181
90	5.13	5.64	192
100	5.40	5.94	202
120	5.91	6.50	222
140	6.39	7.03	239
160	6.83	7.51	255
180	7.25	7.97	271
200	7.64	8.40	284

The Reflecting Telescope.

THE great inconvenience attending the management of long telescopes of the refracting kind, has brought them too much into disuse ever since the reflecting telescope was invented; for one of this sort, six feet in length, magnifies as much as one of the other at an hundred. It was invented by Sir Isaac Newton; but has received considerable improvements since his time; and is now generally constructed in the following manner, which was first proposed by Dr. Gregory.

At the bottom of the great tube T T T T, is placed the large concave mirror D U V F, whose principal focus is at M; and in its middle is a round hole P, opposite to which is placed the small mirror L, concave toward the great one; and so fixed to a strong wire, M, that it may be moved farther from the great mirror, or nearer to it, by means of a long screw on the outside of the tube, keeping its axis still in the same line P m n with that of the great one. Now, since in viewing a very remote object, we can scarce see a point of it but what is at least as broad as the great mirror, we may consider the rays of each pencil, which flow from every point of the object, to be parallel to each other, and to cover the whole reflecting surface D U V F. But, to avoid confusion in the figure, we shall only draw two rays of a pencil flowing from each extremity of the object into the great tube, and trace their progress, through all their reflections and refractions, to the eye f, at the end of the small tube t t, which is joined to the great one. Fig. 4.

Let us then ſuppoſe the object A B to be at ſuch a diſtance, that the rays C y flow from its lower extremity B, and the rays E from its upper extremity A. Then the rays C falling parallel upon the great mirror at D, will be thence reflected, converging in the direction D G; and by croſſing at I in the principal focus of the mirror, they will form the upper extremity I of the inverted image I K, ſimilar to the lower extremity B of the object A B: and paſſing on the concave mirror L, (whoſe focus is at n) they will fall upon it at g, and be thence reflected converging, in the direction g N, becauſe g m is longer than g n; and paſſing through the hole P in the large mirror, they would meet ſomewhere about r, and form the lower extremity d of the erect image a d, ſimilar to the lower extremity B of the object A B. But by paſſing through the plano-convex glaſs R in their way, they form that extremity of the image at b. In like manner the rays E, which come from the top of the object A B, and fall parallel upon the great mirror at F, are thence reflected converging to its focus, where they form the lower extremity K of the inverted image I K, ſimilar to the upper extremity A of the object A B; and thence paſſing on to the ſmall mirror L, and falling upon it at h, they are thence reflected in the converging ſtate h O; and going on thro' the hole P of the great mirror, they would meet ſomewhere about q, and form there the upper extremity a of the erect image a d, ſimilar to the upper extremity A of the object A B: but by paſſing through the convex-glaſs R in their way, they meet and croſs ſooner, as at a, where that point of the erect image is formed. The like being underſtood of all thoſe rays which flow from the intermediate points of the object, between A and B, and enter the tube T T; all the intermediate points of the image between a and b will be formed; and the rays

paſſing

paſſing on from the image through the eye-glaſs S, and through a ſmall hole e in the end of the leſſer tube t t, they enter the eye f, which ſees the image a d (by means of the eye-glaſs) under the large angle c e d, and magnified in length, under that angle from c to d.

In the beſt reflecting teleſcopes, the focus of the ſmall mirror is never coincident with the focus m of the great one, where the firſt image I K is formed but a little beyond it (with reſpect to the eye) as at n; the conſequence of which is, that the rays of the pencils will not be parallel after reflection from the ſmall mirror, but converge ſo as to meet in points about q, e, r; where they will form a larger upright image than a d, if the glaſs R was not in their way: and this image might be viewed by means of a ſingle eye-glaſs properly placed between the image and the eye; but then the field of view would be leſs, and conſequently not ſo pleaſant; for which reaſon the glaſs R is ſtill retained, to enlarge the ſcope or area of the field.

To find the magnifying power of this teleſcope, multiply the focal diſtance of the great mirror by the diſtance of the ſmall mirror from the image next the eye; and multiply the focal diſtance of the ſmall mirror by the focal diſtance of the eye-glaſs; then divide the product of the former multiplication by the product of the latter, and the quotient will expreſs the magnifying power.

I ſhall here ſet down the dimenſions of one of Mr. Short's reflecting teleſcopes, as deſcribed in Dr. Smith's optics.

The focal diſtance of the great mirror 9.6 inches, its breadth 2.3; the focal diſtance of the ſmall mirror 1.5,

its

its breadth 0.6: the breadth of the hole in the great mirror 0.5; the diſtance between the ſmall mirror and the next eye-glaſs 14.2; the diſtance between the two eye-glaſſes 2.4; the focal diſtance of the eye-glaſs next the metal 3.8; and the focal diſtance of the eye-glaſs next the eye 1.1.

One great advantage of the reflecting teleſcope is, that it will admit of an eye-glaſs of a much ſhorter focal diſtance than a refracting teleſcope will; and conſequently it will magnify ſo much the more; for the rays are not coloured by reflection from a concave mirror, if it be ground to a true figure, as they are by paſſing through a convex-glaſs, let it be ground ever ſo true.

The adjuſting ſcrew on the outſide of the great tube fits this teleſcope to all ſorts of eyes, by bringing the ſmall mirror either nearer to the eye, or removing it farther; by which means the rays are made to diverge a little for ſhort-ſighted eyes, or to converge for thoſe of a long ſight.

The nearer an object is to the teleſcope, the more its pencils of rays will diverge before they fall upon the great mirror, and therefore they will be the longer off meeting in points after reflection; ſo that the firſt image I K will be formed at a greater diſtance from the large mirror, when the object is near the teleſcope, than when very remote. But as this image muſt be formed farther from its ſmall mirror than its principal focus n, this mirror muſt be always ſet at a greater diſtance from the large one in viewing near objects, than in viewing remote ones: and this is done by turning the ſcrew on the outſide of the tube, until the ſmall mirror be ſo adjuſted, that the object (or rather its image) appears perfect.

In

In looking through any teleſcope towards an object, we never ſee the object itſelf, but only that image of it which is formed next the eye in the teleſcope: for if a man holds his finger or a ſtick between his bare eye and an object, it will hide part, if not the whole of the object from his view. But if he ties a ſtick acroſs the mouth of a teleſcope, before the object-glaſs, it will hide no part of the imaginary object he ſaw through the teleſcope before, unleſs it covers the whole mouth of the tube: for all the effect will be to make the object appear dimmer, becauſe it intercepts part of the rays. Whereas, if he puts only a piece of wire acroſs the inſide of the tube, between the eye-glaſs and his eye, it will hide part of the object which he thinks he ſees: which proves that he ſees not the real object, but its image. This is alſo confirmed by means of the ſmall mirror L, in the reflecting teleſcope, which is made of opake metal, and ſtands directly between the eye and the object towards which the teleſcope is turned; and will hide the whole object from the eye at e, if the two glaſſes R and S are taken out of the tube.

A Table

A TABLE *of the Apertures, Powers, &c. of Teleſcopes of the Newtonian Conſtruction, to which the Figure of the great Metal is ſuppoſed to be truly Spherical.*

Focal diſtance of the Concave Metal.	Aperture of Concave Metal.	Sir Iſaac Newton's Numbers	Focal diſtance of ſingle eye glaſs.	Magnifying power.
Feet.	In. dec.		In. dec.	
½	0.86	100	0.167	36
1	1.44	168	0.199	62
2	2.43	283	0.236	102
3	3.31	388	0.261	138
4	4.10	476	0.281	171
5	4.85	562	0.297	202
6	5.57	645	0.311	232
7	6.24	———	0.323	260
8	6.89	800	0.334	287
9	7.54	———	0.344	314
10	8.16	946	0.353	340
11	8.76	———	0.362	365
12	9.36	1084	0.367	390
13	9.94	———	0.377	414
14	10.49	———	0.384	437
15	11.04	———	0.391	460
16	11.59	1345	0.397	483
17	12.14	———	0.403	506
18	12.67	———	0.409	528
19	13.20	———	0.414	550
20	13.71	1591	0.420	571
21	14.23	———	0.425	593
22	14.73	———	0.430	614
23	15.21	———	0.435	635
24	15.73	1824	0.439	656

As

AS teleſcopes of Sir Iſaac Newton's conſtruction are now found (particularly by the late exquiſite obſervations of Mr. Herſchell) to perform moſt excellently in the *minutiæ* of aſtronomy, eſpecially if ſmall apertures and long foci are made uſe of, I have added the foregoing table, chiefly taken from Dr. Smith's Optics, and have continued it from 17 to 24 feet focal diſtance of the great mirror: I have alſo annexed to it Sir Iſaac Newton's numbers, by means of which the apertures of reflecting teleſcopes of any conſtruction may be eaſily computed. See Appendix to Gregory's Optics.

It may be neceſſary to mention that the preceding table was conſtructed by uſing the dimenſions of the middle aperture and power of Mr. Hadley's excellent *Newtonian* teleſcope as a ſtandard; viz. the focal diſtance of great mirror 62 ½ inches; aperture of concave metal 5 inches, and power 208 times. Mr. Herſchell, chiefly makes uſe of a Newtonian reflector, the focal diſtance of whoſe great mirror is 7 feet, its aperture 6.25 inches, and powers 227 and 460 times; though ſometimes he uſes a power of 6450 for the fixed ſtars; but he is now conſtructing a teleſcope which will infinitely exceed the former.

If the metals of a *Newtonian* teleſcope are worked as exquiſitely as thoſe in Mr. Herſchell's 7 feet reflector, the higheſt power that ſuch a teleſcope ſhould bear with perfect diſtinctneſs will be given by multiplying the diameter of the great ſpeculum by 74; and the focal diſtance of the ſingle eye-glaſs may be found by dividing the focal diſtance of the great mirror by the magnifying power; thus 6.25 multiplied by 74 is 462, the mag-

nifying power; and 7 multiplied by 12 and divided by 462 is 0.182 of an inch, the focal diſtance of the ſingle eye-glaſs required.---To this I ſhall add

A TABLE *of the Dimenſions and magnifying Powers of* Gregorian *Reflecting Teleſcopes, as conſtructed by* Mr. Short, *computed by* Dr. Smith, *from the Dimenſions of one given before. See page* 261.

Focal diſtance of the great Mirror.	Breadth of the great Mirror.	Focus of the little Speculum.	Breadth of the hole in the great Speculum.	Diſtance between the little Speculum and the firſt eye-glaſs.	Focal diſtance of the glaſs next the metals	Focal diſtance of the glaſs next the eye.	Diſtance between the two glaſſes.	Magnifying power.
In dec.	In dec.	In. dec.	In. dec.	In. dec.	In. dec.	In. dec.	In dec.	
5.65	1.54	1.10	.31	8.54	2.44	.81	1.68	39
9.60	2.30	1.50	.39	14.61	3.13	1.04	2.08	60
15.50	3.30	2.14	.50	23.81	3.94	1.31	2.63	86
36.00	6.26	3.43	.65	41.16	5.12	1.70	3.41	165
60.00	9.21	5.00	.85	68.17	6.43	2.40	4.28	241

The

Plate XVII
Fig. 1.

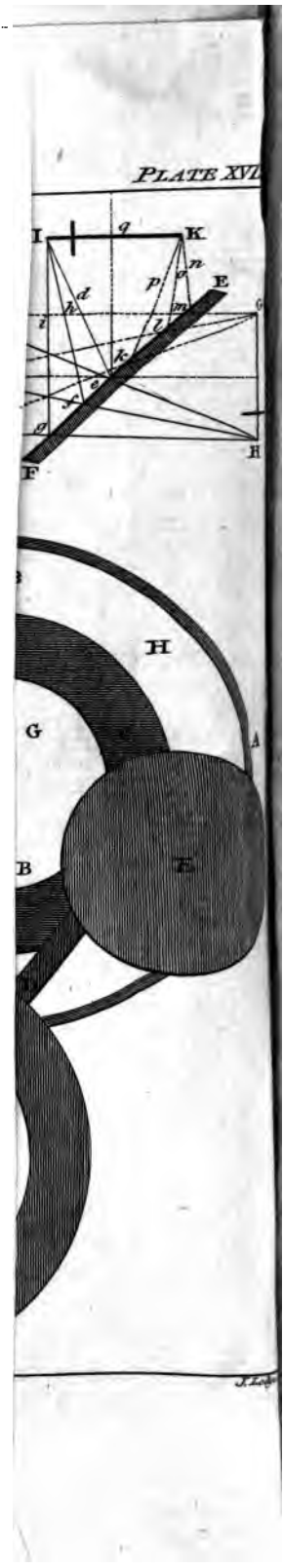
PLATE XVI
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B
E

The Multiplying Glaſs.

THE multiplying glaſs is made by grinding down the round ſide h i k of a convex glaſs A B into ſeveral flat ſurfaces, as h b, b l d, d k. An object C will not appear magnified, when ſeen through this glaſs, by the eye at H; but it will appear multiplied into as many different objects as the glaſs contains plane ſurfaces. For, ſince rays will flow from the object C to all parts of the glaſs, and each plane ſurface will refract theſe rays to the eye, the ſame object will appear to the eye, in the direction of the rays which enter it through each ſurface. Thus a ray g i H, falling perpendicularly on the middle ſurface will go through the glaſs to the eye, without ſuffering any refraction; and will therefore ſhew the object in its true place at C: whilſt a ray a b flowing from the ſame object, and falling obliquely on the plain ſurface b h, will be refracted in the direction b e, by paſſing through the glaſs; and upon leaving it, will go on to the eye in the direction of e H; which will cauſe the ſame object C to appear alſo at E, in the direction of the ray H e, produced in the right line H c n. And the ray c d, flowing from the object C, and falling obliquely on the plane ſurface d k, will be refracted (by paſſing through the glaſs and leaving it at f) to the eye at H; which will cauſe the ſame object to appear at D, in the direction H f m. If the glaſs be turned round the line g l H, as an axis, the object C will keep its place, becauſe the ſurface b l d is not removed; but all the other objects will ſeem to go round C, becauſe the oblique planes, on which the rays a b c d fall, will go round by the turning of the glaſs.

Plate XVII Fig. 1.

The Camera Obſcura.

Fig. 2. THE camera obſcura is made by a convex glaſs C D, placed in a hole of a window-ſhutter. Then, if the room be darkened ſo as no light can enter but what comes through the glaſs, the pictures of all the objects (as fields, trees, buildings, men, cattle, &c.) on the outſide, will be ſhewn in an inverted order, on a white paper, placed at G H in the focus of the glaſs; and will afford a moſt beautiful and perfect piece of perſpective or landſcape of whatever is before the glaſs; eſpecially if the ſun ſhines upon the objects.

If the convex glaſs C D be placed in a tube in the ſide of a ſquare box, within which is the plane mirror E F, reclining backwards in an angle of forty-five degrees from the perpendicular k q, the pencils of rays flowing from the outward objects, and paſſing through the convex glaſs to the plane mirror, will be reflected upwards from it, and meet in points, as I and K (at the ſame diſtance that they would have met at H and G, if the mirror had not been in the way) and will form the aforeſaid images on an oiled paper ſtretched horizontally in the direction I K; on which paper the outlines of the images may be eaſily drawn with a black lead pencil; and then copied on a clean ſheet and coloured by art, as the objects themſelves are by nature. In this machine it is uſual to place a plain glaſs, unpoliſhed, in the horizontal ſituation I K, which glaſs receives the images of the outward objects; and their outline may be traced upon it by a black lead pencil.

The

The tube in which the convex glaſs C D is fixed, muſt be made to draw out, or puſh in, ſo as to adjuſt the diſtance of that glaſs from the plain mirror, in proportion to the diſtance of the outward objects; which the operator does, until he ſees their images diſtinctly painted on the horizontal glaſs at I K.

The forming a horizontal image, as I K, of an upright object AB, depends upon the angles of incidence of the rays upon the plane mirror E. F, being equal to their angles of reflection from it. For, if a perpendicular be ſuppoſed to be drawn to the ſurface of the plain mirror at e, where the ray A a C e falls upon it, that ray will be reflected upwards in an equal angle with the other ſide of the perpendicular, in the line e d I. Again, if a perpendicular be drawn to the mirror from the point f, where the ray A b f falls upon it, that ray will be reflected in an equal angle from the other ſide of the perpendicular, in the line f h l. And if a perpendicular be drawn from the point g, where the ray A c g falls upon the mirror, that ray will be reflected in an equal angle from the other ſide of the perpendicular, in the line g i l. So that all the rays of the pencil a b c, flowing from the upper extremity of the object A B, and paſſing through the convex-glaſs C D, to the plain mirror EF, will be reflected from the mirror, and meet at I, where they will form the extremity I of the image I K, ſimilar to the extremity A of the object A B. The like is to be underſtood of the pencil q r s, flowing from the lower extremity of the object A B, and meeting at K (after reflection from the plain mirror) the rays from the extremity K of the image, ſimilar to the extremity B of the object; and ſo of all the pencils that flow from the intermediate points of the object

object to the mirror through the convex-glaſs. This may be further improved by placing a convex lens of ſix inches focal diſtance, and four inches diameter, or more if it be required longer, between the mirror and the ground glaſs; and though this will reduce the picture, yet it will be more illuminated, and afford a pleaſanter view.

The Solar Teleſcope

IS a curious inſtrument, and is applied to uſe in the following manner. A ſcioptric ball and ſocket being faſtened againſt a hole in the window-ſhutter in a darkened chamber, place the end of a common refracting teleſcope with its object-glaſs and eye-glaſs into the cylindrical hole of the ſcioptric ball, and draw out the tube to its proper length; this being done the teleſcope and ball are moved about till it receives the ſun-beams perpendicular on the object-glaſs through the cylindrical hole of the ball; the tube with the eye-glaſs is then to be adjuſted by moving it either in or out, till the image of the ſun, formed on a white plane or ſcreen, is very diſtinct, large, and luminous.

In this manner the ſun's face is viewed without offence to the eyes, and whatever changes happen therein may be moſt accurately obſerved; the ſpots, which are ſeldom ſeen, even when viewed through ſmall teleſcopes in the common way, are here conſpicuous, and eaſy to be obſerved with all the different circumſtances of the ſpots beginning to appear; their increaſe, diviſion of one into many, or the uniting of many into one, their magnitude and decreaſe, their vaniſhing, and their diſappearance behind the ſun.

An

An eclipſe of the ſun may, by the ſolar teleſcope, be viewed to the greateſt advantage, we having it in our power to repreſent the face of the ſun as large as we pleaſe, conſequently the eclipſe proportionally conſpicuous; alſo the circle of the ſun's diſk may be ſo divided by lines and circles drawn thereon, that the quantity of the eclipſe intimated in digits may this way be exactly determined; alſo the exact time of the beginning, middle, and end thereof, for determining the longitude of the place, are ſeen to the greateſt advantage. The tranſits of Mercury and Venus over the face of the ſun, are exhibited moſt delightfully by this inſtrument: they will here appear truly round, well defined, and very black: their comparative diameters to that of the ſun may this way be obſerved, the direction of their motion, and the times of ingreſs and egreſs are here viewed to the greateſt perfection.

The *Helioſtata* to take off the inconveniences which ariſe from the motion of the earth; in making experiments on the ſolar light, was an excellent invention of Dr. *Graveſand:* it conſiſts of two principal parts, each of which conſiſts of many ſmaller parts. The firſt is a plain metallic ſpeculum, ſupported by a ſtand; the other is a clock which directs the ſpeculum according to the earth's motion, keeping the ſun in the ſame point of view.

The Acromatic Teleſcope.

THIS conſiſts of a double or treble object-glaſs; the double object glaſs conſiſts of a double concave of white flint, and a double convex of crown glaſs. The parts of the lenſes, which are of the ſame ſide of the centers,

centers, may be conceived to act like two priſms, which refract contrary ways; and if the exceſs of refraction in the crown glaſs be ſuch as to deſtroy the divergency of colour cauſed by the flint-glaſs, the incident ray will be refracted without any production of colour: the ſame is true of all the incident rays, and conſequently the image formed in the focus of this compound object-glaſs will be free from colours; or, in other words, by means of the different refractive power of theſe two ſorts of glaſs and their unequal figure, it comes to paſs that all the rays of light incident upon thoſe glaſſes from diſtant radiant objects, will paſs through them in ſuch a manner, that whatever aberration is occaſioned in the heterogeneal rays in refraction through the firſt glaſs, is ſo far corrected by the ſecond, that thoſe rays emerge from it nearly parallel among themſelves, and are converged to one focus, forming an image not ſenſibly compounded or coloured, and therefore are more perfect and diſtinct. It will therefore admit a much larger aperture, and of courſe a greater magnifying power than the common refracting teleſcopes poſſibly can; if the teleſcope be ſhort, the convexity of the lenſes will be conſiderable; and in ſuch caſes it is moſt convenient to combine three lenſes, one concave of white flint-glaſs between two convex of crown-glaſs; but ſtill, where a great magnifying power is wanted, recourſe muſt be had to reflecting teleſcopes: theſe, and all other optical and philoſophical inſtruments, are to be had in their greateſt perfection of that ingenious artiſt Mr. George Adams, *Fleet Street, London*; whoſe aſſiduity in rendering philoſophical reſearches familiar, is well known to the ſcientific.

CLOCK

CLOCK-MAKING.

Of the Terms of Art, or Names by which the Parts of an Automaton are called.

IT is neceſſary that I ſhould ſhew the meaning of the terms which clock-makers uſe, that gentlemen, and others, unſkilled in the art, may know how to expreſs themſelves properly, in ſpeaking; and alſo underſtand what I ſhall ſay in the following treatiſe:

I begin with the more general terms: as, the frame; which is that which contains the wheels, and the reſt of the Work. The pillars and plates are what it chiefly conſiſts of.

Next for the main-ſpring, and its appurtenances. That which the ſpring lies in, is the ſpring-box: that which the ſpring laps about, in the middle of the ſpring-box, is the ſpring-arbor; to which the ſpring is hooked at one end. At the top of the ſpring-arbor, is the endleſs-ſcrew, and its wheel: but in ſpring-clocks, it is a ratchet-wheel, with its click that ſtops it.

That which the main ſpring draweth, and about which the chain or ſtring is wrapped, and which is commonly taper, is the fuſy. In larger work, going with weights, where it is cylindrical, it is called the barrel: the ſmall teeth at the bottom of the fuſy, or barrel, that ſtop it in winding up, is the ratchet. That which ſtops it when wound up, and is for that end driven up by the ſtring, is the gardegut.

The parts of a wheel are, the hoop, or rim; the teeth; the croſs; and the collet, or piece of braſs, ſoldered on the arbor, or ſpindle, on which the wheel is rivetted.

A pinion, is that little wheel which plays in the teeth of the wheel: its teeth (which are commonly 4, 5, 6, 7, 8, &c.) are called leaves, not teeth.

The ends of the ſpindle, are called pivots: the holes in which they run, pivot holes.

The guttered wheel, with iron ſpikes at the bottom, in which the line of ordinary thirty-hour houſe-clocks doth run, is called the pulley.

I need not ſpeak of the dial-plate, the hands, ſcrews, wedges, ſtops, &c.

Thus much for general names, which are common to all parts of a movement.

The moſt uſual movements are watches and clocks. Watches, ſtrictly taken, are all ſuch movements as ſhew the parts of time; and clocks are ſuch as publiſh it, by ſtriking

ſtriking on a bell, &c. But commonly the name of watches is appropriated to ſuch as are carried in the pocket; and that of clock to the larger movements, whether they ſtrike the hour or no. As for watches which ſtrike the hour, they are called pocket-clocks.

The parts of a movement, which I ſhall conſider, are the watch and clock parts.

The watch part of a movement, is that which ſerveth to the meaſuring the hours: in which the firſt thing I ſhall conſider is the balance; whoſe parts are the rim, which is the circular part of it; the verge is its ſpindle, to which belong the two pallets, or leaves, which play in the teeth of the crown-wheel: in pocket watches, that ſtrong ſtud, in which the lower pivot of the verge plays, and in the middle of which, one pivot of the balance-wheel plays, is called the pottance. The bottom of this is called the foot; the middle part (in which the pivot of the balance-wheel turns) is called the noſe; the upper part, the ſhoulder of the pottance. The piece which covers the balance, and in which the upper pivot of the balance plays, is the cock. The ſmall ſpring in pocket watches underneath the balance, is the regulator, or pendulum-ſpring.

The parts of a pendulum are the verge, pallets, and cocks, as before. The ball in long pendulums, the bob in ſhort ones, is the weight at the bottom: the rod, or wire is plain. The term peculiar to the royal ſwing, are the pads, which are the pallets in others, and are fixed on the arbor; the fork is alſo fixed to the arbor, and about ſix inches below, catcheth hold on the rod, at a flat piece of braſs, called the flat, in which the lower end of the ſpring is faſtened.

The names of the wheels next follow: the crown-wheel in ſmall pieces, and the ſwing wheel in royal pendulums, is that wheel which drives the balance, or pendulum.

The contrate-wheel, is that wheel in pocket-watches, and others, which is next to the crown-wheel, whoſe teeth and hoop lie contrary to thoſe of other wheels; whence it hath its name.

The great wheel, or firſt-wheel, is that which the fuſy, &c. immediately driveth. Next it are the ſecond-wheel, third-wheel, &c.

Next followeth the work between the frame and dial-plate: and firſt, is the pinion of report; which is that pinion which is commonly fixed on the arbor of the great wheel, and in old watches uſed to have commonly but four leaves; which driveth the dial-wheel, and this carrieth about the hand.

The laſt part which I ſhall ſpeak of is the clock, which is that part which ſerveth to ſtrike the hours: in which, I ſhall firſt ſpeak of the great or firſt wheel; which is that which the weight or ſpring firſt drives. In thirty-hour clocks, this is commonly the pin-wheel: this wheel, thus with pins, is called the ſtriking-wheel, or pin-wheel.

Next to this ſtriking-wheel, followeth the detent-wheel, or hoop-wheel, it having a hoop almoſt round it, in which is a vacancy, at which the clock locks.

The next is the third, or fourth-wheel (according as it is diſtant from the firſt wheel) called alſo the warning-wheel.

And

And laſtly, is the flying pinion, with a fly, or fan, to gather air, and ſo bridle the rapidity of the clock's motion.

Beſides theſe, there are the pinion of report, of which before, which driveth round the locking wheel, called alſo the count-wheel, with eleven notches in it commonly, unequally diſtant from one another, to make the clock ſtrike the hours of 1, 2, 3, &c.

Thus much for wheels of the clock part.

The detents are thoſe ſtops which, by being lifted up, or let fall down, do lock and unlock the clock in ſtriking.

The hammers ſtrike the bell: the hammer-tails are what the ſtriking-pins draw back the hammers by.

Latches are what lift up, and unlock the work.

Catches are what hold by hooking, or catching hold of.

The lifting pieces do lift up, and unlock the detents, in the clock part.

The train is the number of beats or vibrations which the watch maketh in an hour, or any other certain time.

There are beſide theſe, divers other terms which clock-makers uſe in various ſorts of pieces; as the ſnail or ſtep-wheel, in repeating-clocks, the rack, the ſafeguards, the ſeveral

ſeveral levers, lifters, and detents: but it would be tedious, and it is needleſs to mention the particulars.

For the better underſtanding theſe terms of art, and the parts of a clock, I have repreſented them to the eye: in which, two diſtinct parts may be obſerved; the watch, and the clock part.

The wheels, &c. on the right hand, is the watch part; they on the left, the clock.

Plate XVIII. Fig. 2.

D.D. The ſpring-boxes of the watch and clock part.

E. E. The great wheel of each part.

F. F. The fuſy of each part, about which the chain or ſtring is wrapped.

o. o. The click and ſpring of each part.

g. g. The ratchet of each part.

a. The hoop, or rim of the ſecond wheel.

b The croſs thereof.

c. The pinion.

d. The third-wheel.

x. The pallet-wheel.

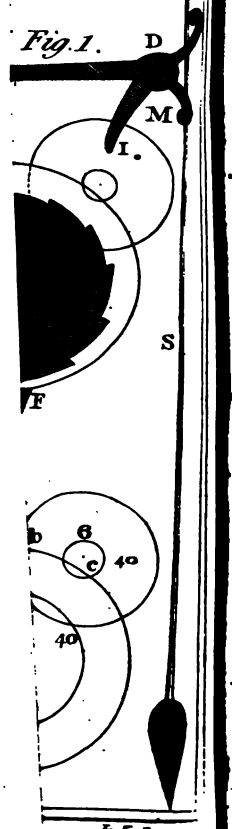
L. The pin-wheel, with the ſtriking-pins e. e. e.

m. The hoop-wheel.

n. The

PLATE XI

Plate XVIII. Fig. 2.



n. The warning wheel, or fourth-wheel.

O. The detent.

P. The lifting-piece.

2. The fan, and flying-pinion.

R. The bell.

S. The hammer.

T. The hammer-tail.

y. The hammer-ſpring.

V. V. The chain, or ſtring of the watch and clock.

The pendulum conſiſts of, 1. The rod. 2. The fork. 3. The flat. 4. The great ball. 5. The corrector, or regulator; being a contrivance of very great uſe to bring the pendulum to its niceſt vibrations, and is fixed on the verge at the end of the pallets 5. 5.

To find the Length of a Pendulum that ſhall make any Number of Vibrations in a Minute, and vice verſa.

A PENDULUM whoſe length is 39.2 inches, from the point of ſuſpenſion to the center of oſcillation, makes 60 vibrations in a minute: this is called ſtandard length. For any other number of vibrations in a minute, ſay as the ſquare of the given number of vibrations is to the

ſquare

ſquare of 60, ſo is the length of the ſtandard to the length ſought. Thus, ſuppoſe the given number of vibrations to be 30 per minute: the ſquare of 30 is 900, and the ſquare of 60 is 3600: then, as 900 is to 3600, ſo is 39.2 to 156.8: ſo that the length required for 30 vibrations per minute is 156.8 inches.

If the length of the pendulum be given, and the number of vibrations it makes in a minute might be required; ſay, as the given length is to the ſtandard length (39.2 inches) ſo is the ſquare of 60 vibrations to the ſquare of the number required: the ſquare root of which ſhall be the number of vibrations made by the pendulum in a minute. Thus, ſuppoſe the given length to be 156.8 inches: as 156.8 is to 39.2, ſo is 3600 (the ſquare of 60) to 900; the ſquare root of which is 30, the number of vibrations that this pendulum will make in a minute.

The length of a pendulum that would make only one vibration in a minute is 3920 yards, or 141120 inches: and the length of a pendulum that would make 240 vibrations in a minute (or 4 in a ſecond) is 2.45 inches.

In theſe calculations, it is ſuppoſed that the weight of the pendulum-rod bears little or no ſenſible proportion to the weight of the ball. But as this cannot be the caſe in practice, the center of oſcillation will always be further from the point of ſuſpenſion than the calculation makes it; and this muſt be found by trial.

To divide the Circumference of a Circle into any given Number of equal Parts, whether even or odd.

As there are very uncommon and odd numbers of teeth in ſome of the wheels of the aſtronomical clocks, and which, conſequently, could not be cut by any common engine uſed by clock-makers for cutting the numbers of teeth in their clock-wheels, I thought proper to ſhew how to divide the circumference of a circle into any given odd or even number of equal parts, ſo as that number may be laid down upon the dividing-plate of a cutting engine.

There is no odd number, but from which, if a certain number be ſubtracted, there will remain an even number, eaſy to be ſubdivided: thus, ſuppoſing the given number of equal diviſions of a circle on the dividing-plate to be 69; ſubtract 9, and there will remain 60.

Every circle is ſuppoſed to contain 360 degrees: therefore ſay, as the given number of parts in the circle, which is 69, is to 360 degrees, ſo is 9 parts to the correſponding arc of the circle that will contain them: which arc, by the rule of three, will be found to be 46 95-100. Therefore, by the line of chords on a common ſcale, or rather on a ſector, ſet off 46 95-100 (or 46 9-10) degrees with your compaſſes, in the periphery of the circle, and divide that arc or portion of the circle into 9 equal parts, and the reſt of the circle into 60; and the whole will be divided into 69 equal parts, as was required.

Again, ſuppoſe it were required to divide the circumference of a circle into 83 equal parts; ſubtract 3, and

80 will remain. Then as 83 parts are to 360 degrees, ſo (by the rule of proportion) are 3 parts to 13 degrees and one hundredth part of a degree; which ſmall fraction may be neglected. Therefore, by the line of chords, and compaſſes, ſet off 13 degrees in the periphery of the circle, and divide that portion or arc into 3 equal parts, and the reſt of the circle into 80; and the thing will be done.

Once more, ſuppoſe it were required to divide a given circle into 365 equal parts: ſubtract 5, and 360 will remain. Then, as 365 parts are to 360 degrees, ſo are 5 parts to 4 93-100 degrees. Therefore, ſet off 4 93-100 (or 4 9-10) degrees in the circle; divide that ſpace into 5 equal parts, and the reſt of the circle into 360; and the whole will be divided into 365 equal parts, as was required.

I have often found this rule or method very uſeful in dividing circles into an odd number of equal parts, or wheels into odd numbers of equal ſized teeth with equal ſpaces between them: and now I find it as eaſy to divide any given circle into any odd numbers of equal parts, as to divide it into any even number. For this purpoſe I prefer the line of chords on a ſector, to that on a plain ſcale; becauſe the ſector may be opened ſo, as to make the radius of the line of chords upon it equal to the radius of the given circle, unleſs the radius of the circle exceed the whole length of the ſector when it is opened ſo as to reſemble a ſtraight ruler, or ſcale; and this is what very ſeldom happens.

Any perſon who is uſed to handle the compaſſes, and the ſcale or ſector, may very eaſily, by a little practice, take

take off degrees, and fractional parts of a degree, by the accuracy of his eye, from a line of chords, near enough the truth for the above-mentioned purpoſe.

Suppoſing the Diſtance between the Centers of two Wheels, one of which is to turn the other, be given; that the Number of Teeth in one of theſe Wheels is different from the Number of Teeth in the other, and it is required to make the Diameters of theſe Wheels in ſuch Proportion to one another as their Numbers of Teeth are, ſo that the Teeth in both Wheels may be of equal Size, and the Spaces between them equal, that either of them may turn the other eaſily and freely,—it is required to find their Diameters.

HERE it is plain, that the diſtance between the centers of the wheels is equal to the ſum of both their radii in the working parts of the teeth. Therefore as the number of teeth in both wheels, taken together, is to the diſtance between their centers, taken in any kind of meaſure, as feet, inches, or parts of an inch; ſo is the number of teeth in either of the wheels to the radius or ſemi-diameter of that wheel, taken in the like meaſure, from its center to the working part of any one of its teeth.

Thus, ſuppoſe the two wheels muſt be of ſuch ſizes as to have their diſtances between their centers 5 inches; that one wheel is to have ſeventy-five teeth, and the other to have 33, and that the ſizes of the teeth in both the wheels is equal, ſo that either of them may turn the other. The ſum of the teeth in both wheels is 108; therefore ſay, as 108 teeth is to 5 inches, ſo is 75 teeth to 3 inches and 47 hundred parts of an inch: and as 108

is to 5, ſo is 33 to 1 inch and 53 hundred parts of an inch. So that from the center of the wheel of 75 teeth to the working part of any tooth in it, is 3 inches and 47 hundred parts of an inch; and, from the center of the wheel of 33 teeth to the working part of either of its teeth, is 1 inch and 53 hundred parts of an inch.

General preliminary Rules and Directions for Calculation.

FOR the more clear underſtanding this, it muſt be obſerved, that thoſe automata (whoſe calculation I chiefly intend) do by little interſtices, or ſtrokes, meaſure out long portions of time. Thus the ſtrokes of the balance of a watch do meaſure out minutes, hours, days, &c.

Now to ſcatter thoſe ſtrokes amongſt wheels and pinions, and to proportionate them, ſo as to meaſure time regularly, is the deſign of calculation.

And in the firſt place, you are to know, that any wheel being divided by its pinions, ſhews how many turns that pinion hath to one turn of that wheel. Thus a wheel of 60 teeth driving a pinion of 6, will turn round the pinion 10 times in going round once. 6)60(10.

From the fuſy to the balance the wheels drive the pinions; and conſequently the pinions run faſter, or go more turns, than the wheels they run in. But it is contrary from the great wheel to the dial-wheel. Thus, in the laſt example, the wheel drives round the pinion 10 times: but if the pinion drove the wheel, it muſt turn 10 times to drive the wheel round once.

Before

Before I proceed further, I muſt ſhew how to write down the wheels and pinions; which may be done either as vulgar fractions, or in the way of diviſion in vulgar arithmetic. For example, a wheel of 60 moving a pinion of 5, may be ſet down 60-5ths; or thus 5)60: where the uppermoſt figure 60, or numerator, is the wheel, the lowermoſt or denominator, is the pinion: or in the latter example, the firſt figure is the pinion, the next without the hook the wheel.

The number of turns which the pinion hath in one turn of the wheel, is ſet without a hook on the right hand, as 5)60(12; i. e. a pinion 5 playing in a wheel of 60, moveth round 12 times in one turn of the wheel.

A whole movement may be noted thus, $\frac{4}{36}$ $\frac{55}{5}$ $\frac{45}{5}$ $\frac{40}{5}$ ſeventeen notches in the crown-wheel. Or rather becauſe eaſier to mean capacities, as you ſee here in the margin: where the uppermoſt number above the line is the pinion of report 4, the dial-wheel 36, and 9 turns of the pin of report. The ſecond number (under the line) is 5 the pinion, 55 is the great wheel, and 11 turns of the pinion it driveth. The third numbers are the ſecond wheel, &c. The fourth the contrate wheel, &c. And the ſingle number 17 under all, is the number of the crown-wheel.

4)36(9
5)55(11
5)45(9
5(40(8
17

By knowing the number of turns which any pinion hath in one turn of the wheel it worketh in, you may alſo find out how many turns a wheel or pinion hath at a greater diſtance; as the contrate wheel, crown wheel, &c. For it is but multiplying together the quotients (by the quotients

quotients, I commonly mean the number of turns; which number is ſet on the right hand, without the hook, as is ſhewn in the laſt example) and the number produced is the number of turns. An example will make what I ſay plain: let us chuſe three numbers here ſet down; the firſt of which hath 11 turns, the next 9, and the laſt 8. If you multiply 11 and 9, it produceth 99, for 9 times 11 is 99, that is in one turn of the wheel 55, there are 99 turns of the ſecond pinion 5, or the wheel 40, which runs concentrical, or on the ſame arbor with the ſecond pinion 5. For as there are 11 turns of the firſt pinion 5, in one turn of the great wheel 55, or (which is the ſame) of the ſecond wheel 45, which is on the ſame ſpindle with that pinion 5; ſo there are 9 times 11 turns in the ſecond pinion 5, or wheel 40 in 1 turn of the great wheel 55. If you multiply the laſt quotient 8 (that is, 8 times 99 is 792) it ſhews the number of turns which the third and laſt pinion 5 hath. So that this third and laſt pinion turns 792 times in one turn of the firſt wheel 55. Another example will make it ſtill more plain. The example is in the margin. The turns are 10, 9, and 8. Theſe multiplied as before, run thus, viz. 10 times 9 is 90, that is the pinion 6 (which is the pinion of the third wheel 40, and runs in the ſecond wheel 54) turns 90 times in one turn of the firſt wheel 80. This laſt product 90 being multiplied by 8, produces 720; that is, the pinion 5 (which is the pin of the crown-wheel 15) turns 720 times in one turn of the firſt wheel of 80 teeth.

5) 55 (11
5) 45 (9
5) 40 (8

8) 80 (10
6) 54 (9
5) 40 (8
15

A whole

A whole Movement of a modern Pocket Watch may be noted thus:

	Teeth	Leaves
The great wheel -	48 -	12
Centre wheel -	54 -	6
Third wheel -	48 -	6
Contrate wheel -	48 -	6
Balance wheel -	15 -	2 pallets.

Thus when the watch is wound up, the chain from the ſpring exerts a force upon the fuſee, which gives motion to all parts of the machine.

The great wheel on the fuſee having 48 teeth, and driving the center wheel by a pinion of 12 leaves, make the center wheel turn round four times in one turn of the fuſee. Thus alſo we may account for all others; for,

If 12) 48 (4 = Turns of the center wheel,
So 6) 54 (9 = Turns of the third wheel.
6) 48 (8 = Turns of the contrate wheel,
6) 48 (8 = Turns of the balance.

Then multiply theſe ſeveral quotients together ſucceſſively, and you will find the turns of each of thoſe wheels reſpectively in one turn of the fuſee.

Thus 1 turn of the fuſee, or great wheel; 4 mul. 1 = to 4 turns of the center wheel; 9 mul. 4, mul. 1 = to 36 turns of the third wheel; 8 mul. 9, mul. 4. mul. 1 = to 288 turns of the contrate wheel; 8 mul. 9 mul. 4 mul. 1 = to 2304 turns of the balance wheel.

And

And the balance wheel having 15 teeth, and each ſtriking a pallet twice in one revolution, there will be thirty ſtrokes upon the axis of the balance, which are called the beats of the balance; conſequently there muſt be 2304 mul. 30 = 69120 ſtrokes or beats in one turn of the fuſee or great wheel.

But though theſe particulars are neceſſary to be premiſed, our principal regard, in the diviſion of time, is to be paid to the center wheel. For this wheel alone is that upon which both the hour and minute-hand is moved or carried round upon the face of the watch, to ſhew the hour of the day, and the minute of the hour, &c.

If we would find out the number of beats of the balance in the time of thoſe turns above-mentioned, it muſt be noted, that as the watch goes thirty hours, and the minute-hand, and conſequently the center wheel goes round once in an hour, the ſaid center wheel will have thirty turns in the time of the watch's going round; and becauſe it hath four turns in one of the fuſee, therefore we muſt ſay 4)30(= 7 ½ = the number of turns of the fuſee, in winding up the watch. Whence we find 69120 mul. 7, 5 = 518400 = the number of the beats in 30 hours. Then if we divide 518400 by 30, the quotient will be 17280 = number of beats in an hour, which is called the train of a watch; which train is called ſwifter or ſlower, as the number of beats in an hour is more or leſs: ſo again, if we divide this train 17280 by 3600, the ſeconds in an hour, the quotient will be almoſt 5, or almoſt 5 beats per ſecond in ſuch a watch.

By

By this analyſis, it is eaſy to form an idea of the manner of calculation for the numbers of the teeth and leaves for the ſeveral wheels and pinions in a watch; which may further be illuſtrated by an example of a train 14400, which will beat quarter ſeconds, becauſe ſuch a train is uſeful in many philoſophical caſes, as well as in the juſt diviſion of time.

Suppoſe the intended watch is to go 32 hours; then it will be found that 14400 multiplied by 32 = 460800 = the beats of the balance in 32 hours. And if the number of turns in the fuſee be 8, then 8)460800(= 57600 = the beats in one turn of the fuſee.

Again, ſuppoſe the number of teeth in the balance-wheel be 15, there will be 30 beats in one turn of this wheel; then 30)57600(= 1920, which will be the number ariſing from the continued multiplication of all the quotients of the wheels, divided by the pinions they drive from the great wheel to the balance-wheel, as has been already exemplied.

Our next care is to break this number into four convenient ſmall numbers, which, multiplied together, ſhall make the ſame number 1920. Then I ſay, 4)1920(= 480. Again, I ſay, 6)480(= 80: and as I plainly ſee that 80 = 8 multiplied by 10, conſequently the four numbers ſought for are 4, 6, 8, and 10; becauſe, multiply theſe numbers together, they will make exactly 1920: thus, 4 mul. 6 mul. 8. mul. 10 = 1920.

The quotients thus inveſtigated, we may eaſily find what large numbers, divided by ſmall ones, will pro-

duce the ſaid quotients: thus 12)48(= 4. Conſequently, if we allow 48 teeth to the great wheel on the fuſee, it muſt drive a pinion of 12 on the center-wheel. So again, if for the quotient 6, we chooſe 54 and 9 (thus 9)54(= 6) it ſhews that the teeth of the center wheel may be 54; and it muſt drive a pinion of 9 on the third wheel. Or if, inſtead of 54 and 9, we chuſe 48 and 8, it will anſwer the ſame end: thus 8)48(=6. As for the quotient 10, we may eaſily perceive that 50 and 5 will anſwer the enquiry: thus 5)50(= 10; ſo the third wheel having 50 teeth, muſt drive a pinion of 5 on the contrate wheel: where note, that if the ſaid wheel has 40 or 60 teeth, and drive a pinion of 4 or 6, we ſhall find the ſame number of turns exactly: and as for the quotient 8, we have the number 48 and 6: thus, 6)48(=8; or, 7)56(=8; or, 5)40(=8: therefore, if the contrate wheel be allowed 40, or 48, or 56 teeth, it will drive a pinion of 5, 6, or 7 leaves on the balance-wheel.

Thus it is to determine and adjuſt all the wheels and pinions in the body of a watch, from the fuſee to the balance, ſo far as to relate to the minute of an hour, and to the ſeconds and quarter ſeconds of a minute.

Having ſhewed, as clearly as I can, the way of calculating numbers for the watch-part, I ſhall alſo briefly ſhew the principles of the ſtriking part.

Altho' this part conſiſts of many wheels and pinions, yet reſpect needs to be had only to the count-wheel, ſtriking-wheel, and detent-wheel, which move round in this proportion; the count-wheel B moveth round commonly once in 12 or 24 hours. The detent-wheel' moves

Fig. 4

moves round every ſtroke the clock ſtriketh; ſometimes but once in two ſtrokes. From whence it follows,

1. That as many pins as are in the pin-wheel, ſo many turns hath the detent-wheel in one turn of the pin-wheel: or (which is the ſame) the pins of the pin-wheel are the quotient of that wheel, divided by the pinion of the detent-wheel. But if the detent-wheel moveth but once round in two ſtrokes of the clock, then the ſaid quotient is but half the number of pins.

2. As many turns of the pin-wheel as are required to perform the ſtrokes of 12 hours (which are 78) ſo many turns muſt the pinion of report have, to turn round the count-wheel once. Or thus: Divide 78 by the number of ſtriking-pins, and the quotient thereof ſhall be the quotient for the pinion of report and the count-wheel. All this is, in caſe the pinion of report be fixed to the arbor of the pin-wheel, as is very commonly done.

All this I take to be very plain: or, if it be not, the example in the margin will clear all difficulties. Here the locking-wheel A is 48, the pinion of report is 8, the pin-wheel is 78, the ſtriking-pins are 13: and ſo the reſt. I need only to remark here, that 78 being divided by the 13 pins, gives 6; which is the quotient of the pinion of report O, as was before hinted; and the notches of the plate B ſerve to let the locking-piece C fall into; which comes from the detent D.

8)48(6
6)78(13 pins
6)60(10
6)48(8

As for the warning-wheel and flying-pinion, it m
ters little what numbers they have, their uſe being o
to bridle the rapidity of the motion of the other whe

Numbers of ſeveral Sorts of Movements.

Although I have before given ſuch plain directions
may, I hope accompliſh a young practitioner in t
art of calculation, yet it may be very convenient to
down ſome numbers fit for ſeveral movements; part
to be as examples to exerciſe the young reader; a
partly to ſerve ſuch who want leiſure or underſtandi
to attain to the art of calculation.

Numbers of an Eight-Day Piece, with 16 *Turns of Barrel: the Pendulum vibrates Seconds, and ſhews Minutes, Seconds, &c.*

Watch part.	Clock part.
8)96	8)78
8(60—40)40—6)72	7)56 8 pins
7)56	7)49
30	7)49

In the watch part, the wheel 60 is the minute-whee
which is ſet in the middle of the clock, that its ſpind
may go through the middle of the dial-plate, to car
the minute-hand.

Fig. 3. Alſo, on this ſpindle is the wheel 40, a, which dri
eth another wheel b of 40; which laſt hath a pinion 6,
which driveth round that of 72 d in 12 hours. Note tw
things

things: 1. That the two wheels 40, are of no other uſe but to ſet the pinion 6 at a convenient diſtance from the minute-wheel, to drive the wheel 72, which is concentrical with the minute-wheel; for a pinion 6 driving a wheel 72, would be ſufficient, if the minute-hand and hour-hand had two different centers. 2. Theſe numbers, 60—40)40—6(72, ſet thus, ought, according as above, to be thus read, viz. The wheel 60 hath another wheel 40, on the ſame ſpindle; which wheel 40, divideth (playeth in, or turns round) another wheel 40; which hath a pinion 6 concentrical with it; which pinion driveth or divideth a wheel of 72; for a line parting two numbers (as 60—48) denoteth thoſe two numbers to be concentrical, or to be placed upon the ſame ſpindle. And when two numbers have a hook between them (as 48)48) it ſignifies one to run in the other.

In the ſtriking part, there are 8 pins on the ſecond-wheel 56. The count-wheel may be fixed unto the great wheel, which goeth round once in 12 hours.

A Piece of 32 Days, with 16 Turns both Parts: the Watch ſheweth Hours, Minutes, and Seconds; and the Pendulum vibrateth Seconds.

Watch part, with 16 turns.	Striking part, with 16 turns.
16)96	10)130
9)72	8)96 { 24 pins
8)60—48)48—6)72	{ 12)39
7)56	6)72 double hoop.
——	6)60
30	

The

A Year-Piece of 384 *Days, with Turns, Pendulums, and Motions, as before.*

Watch.	Clock.
12)108	10)120
9)72	8)96—36)9
8)64	6)78.26 pins
8)60—48)48—6)72	6)72 double hoop
7)56	6)60
30	

If you had rather have the pinion of report on the ſpindle of the pin-wheel, it muſt be 13)39.

A Piece of 30 *Hours, Pendulum about* 6 *Inches.*

Watch.	Clock.
12)48	8)48
6)78	6)78 13 pins
6)60	6)60
6)42	6)48
15	

A 30 *Hour-Piece, to ſwing Seconds.*

Watch part.	Clock part.
6)90	6)78 13 pins
6)72	6)54
30	7)49

Repeating Work.

LET A be a piece of braſs cut down in twelve ſpiral ſteps, in form of a ſnail (from whence it takes its name) as in the figure; let this be fixed on the ſocket of the hour-wheel; and B G L F the rack, with 14 teeth, turning on its center L, having a ſpring H to force the end F upon Fig. 1.

upon the ſteps of the ſnail A, when at liberty. The pin at I in the motion-wheel, takes hold of the lifting-piece D M K; and the end K, in riſing, lifts up the hook C, which lies in the teeth of the rack, and riſes until the teeth are diſengaged from it; the end F then falls down, and ſtops againſt the ſteps of the ſnail A, which in the figure is at two o'clock.

The arbor of the third or gathering-wheel m (fig. 2.) comes thro' the plate on which the pallet E m (fig. 1.) is fixed; a turn of which anſwering to one ſtroke of the hammer, gathers the rack up one tooth: 12 ſteps of the ſnail anſwer 12 teeth in the rack; and when the gathering pallet E m, has taken as many teeth in the rack as the number of the hour, the end E of the pallet ſtops againſt a pin in the rack at G, and is there at reſt until the hook C is again lifted out of the teeth by the lifting-piece, as before.

When the hook C is lifted out of the teeth of the rack, the clock would ſtrike continually, as the hook being out of the teeth, prevents the rack being gathered up; but that the end K of the lifting-piece has a ſmall arm which goes through the plate, and a pin in the wheel n, which ſtops againſt it in ſuch a manner, that when the lifting-piece is ſuffered to fall by the pin I, having gone paſt the pin in the rim of the wheel n, it is clear of the arm at the end of the lifting-piece K; the wheel being then at liberty, the clock ſtrikes until the gathering pallet E ſtops againſt the pin of the rack at G, as before. By putting a ſmall ſtring to the top-end of the ſpring S, to come thro' the caſe, it may be made to ſtrike the laſt hour at any time, except when on the warning.

SEPTEMBER
OCTOBER
AUGUST
Libra
Balance
Virgo
Virgin
Leo

ASTRONOMY.

BIBLIOTHECA BODLEIANA

A brief Deſcription of the Solar Syſtem.

THE Sun, with the planets and comets which move round him as their center, conſtitute the ſolar ſyſtem. Thoſe planets which are near the Sun, not only finiſh their circuits ſooner, but likewiſe move faſter in their reſpective orbits, than thoſe which are more remote from him. Their motions are all performed from weſt to eaſt, in orbits nearly circular. Their names, diſtances, bulks, and periodical revolutions, are as follow: — Plate XIX.

The Sun, an immenſe globe of fire, is placed near the common center of all the planets, and turns round his axis in 25 days 6 hours, as is evident by the motion of ſpots ſeen on his ſurface; which have often been remarked to keep this time before they diſappeared. His diameter is computed to be 763,000 miles: all planets ſeen from him move the ſame way, and according to the order of the ſigns in the graduated circle, Aries, Taurus, Gemini, Cancer, &c. which repreſent the great ecliptic in the heavens; but as ſeen from any one planet, the reſt appear ſometimes to go backward, and ſometimes forward, and ſometimes to ſtand ſtill, not in circles or ellipſes, but in looped curves, which never return into themſelves.

Mercury. Mercury, the neareſt planet to the Sun, goes round him in 87 days 23 hours of our time nearly; which is the length of his year. But being ſeldom ſeen, and no ſpots appearing upon his ſurface or diſk, the time of his rotation on his axis, or the length of his days and nights, are as yet unknown. His diſtance from the Sun is computed to be 32,000,000 of miles, and his diameter 2,600. In his courſe round the Sun, he moves at the rate of 95,000 miles every hour. His light and heat from the Sun are almoſt ſeven times as great as ours; and the Sun appears to him near ſeven times as large as to us.

His orbit is inclined ſeven degrees to the ecliptic; and that node from which he aſcends northward above the ecliptic, is in the 14th degree of Taurus; the oppoſite in the 14th degree of Scorpio. The Earth is in theſe points on the 6th of November and 4th of May, new ſtile; and when Mercury comes to either of his nodes, when he is between the Earth and Sun in the nearer part of his orbit, he will appear to paſs over the diſk or face of the ſun, like a dark round ſpot; but in all other parts of his orbit, his conjunctions are inviſible, becauſe he either goes above or below the Sun.

According to Mr. Whiſton, he will appear on the Sun's diſk in 1789, Dec. 6th, at 3h. 55m. in the afternoon; and in 1799, May 7th, at 2h. 34m. in the afternoon. There will be ſeveral intermediate tranſits, but none of them viſible in this latitude.

Venus. Venus, the next planet in order, is computed to be 59 millions of miles from the Sun; and by moving at the rate

rate of 69,000 miles every hour in her orbit, ſhe goes round the Sun in 224 days 17 hours of our time nearly; in which, tho' it be the full length of her year, ſhe has only nine days one quarter, according to the beſt obſervations; ſo that, to her, every day and night together, is as 24 1-3d days and nights with us. This odd 1-4th of a day in every year, makes every fourth year to Venus, as the like does to our Earth. Her diameter is 7,906 miles; and, by her diurnal motion, the inhabitants about her equator are carried 43 miles every hour, beſides the 69,000 above mentioned.

Venus's orbit is inclined $3\frac{1}{2}$ degrees to the Earth's, and croſſes it in the 14th degree of Gemini and of Sagittarius.

The axis of Venus is inclined 75 degrees to the axis of her orbit; which is $51\frac{1}{2}$ degrees more than the Earth's axis is inclined to the axis of the ecliptic; and therefore her ſeaſons vary much more than ours do. The north pole of her axis inclines toward the 20th degree of Aquarius; the Earth's to the beginning of Cancer; conſequently the northern parts of Venus have ſummer in the ſigns where thoſe of the Earth have winter, and *vice verſa*.

As her annual revolution contains only $9\frac{1}{4}$ of her days, the Sun will always appear to go thro' a whole ſign, or 12th part of her orbit, in little more than three quarters of her natural day, or nearly in $13\frac{3}{4}$ of our days and nights.

She ſhews the ſame appearances to us regularly every eight years; her conjunctions, elongations, and times of

riſing and ſetting, being very nearly the ſame on the ſame days as before.

Earth. The Earth is the next planet above Venus in the ſyſtem. It is 82,000,000 of miles from the ſun, and goes round him in 365 days 5 hours 49 minutes, from any equinox or ſolſtice to the ſame again; but from any fixed ſtar to the ſame again, as ſeen from the Sun, in 365 days 6 hours and 9 minutes; the former being the length of the tropical year, and the latter the length of the ſydereal. It travels at the rate of 58,000 miles every hour; which motion, tho' 120 times ſwifter than that of a cannon-ball, is little more than half as ſwift as Mercury's motion in his orbit. The Earth's diameter is 7,970 miles; and by turning round its axis every 24 hours from weſt to eaſt, it cauſes an apparent diurnal motion of all the heavenly bodies from eaſt to weſt. By this rapid motion of the earth on its axis, the inhabitants about the equator are carried 1,042 miles every hour, while thoſe on the parallel of London are carried only about 580, beſides the 58,000 miles by the annual motion above mentioned, which is common to all places whatever. The Earth's axis makes an angle of $23\frac{1}{2}$ degrees with the axis of its orbit; and keeps nearly the ſame oblique direction, inclining towards the ſame fixed ſtars throughout its annual courſe, which cauſes the return of ſpring, ſummer, autumn, and winter.

Moon. The Moon is not a planet, but only a ſatellite or attendant of the Earth, going round the Earth from change to change, in 29 days 12 hours and 44 minutes; and round the Sun with it every year. The Moon's diameter is 2,180 miles; and her diſtance from the Earth's center 24,000. She goes round her orbit in 27 days

days 7 hours 43 minutes, moving about 2,290 miles every hour; and turns round her axis exactly in the time that ſhe goes round the earth; which is the reaſon of her keeping always the ſame ſide towards us; and that her day and night together is as long as our lunar month.

The Moon is an opaque globe, like the Earth, and ſhines only by reflecting the light of the Sun; therefore, whilſt that half of her which is towards the Sun is enlightened, the other half muſt be dark and inviſible. Hence, ſhe diſappears when ſhe comes between us and the Sun, becauſe her dark ſide is then towards us. When ſhe is gone a little forward, we ſee a little of her enlightened ſide; which ſtill increaſes to our view as ſhe advances forward, until ſhe comes to be oppoſite to the Sun, and then her whole enlightened ſide is towards the Earth; and ſhe appears with a round illuminated orb, which we call the Full Moon; her dark ſide being then turned away from the Earth. From the full, ſhe ſeems to decreaſe gradually as ſhe goes through the other half of her courſe; ſhewing us leſs and leſs of her enlightened ſide every day, till her next change or conjunction with the ſun; then ſhe diſappears, as before.

This continual change of the Moon's phaſes demonſtrates, that ſhe ſhines not by any light of her own; for if ſhe did, being globular, we ſhould always ſee her with a round full orb, like the Sun. She has very little difference of ſeaſons, her axis being almoſt perpendicular to the ecliptic. What is very ſingular, one half of her has no darkneſs at all; the Earth conſtantly affording it a ſtrong light in the Sun's abſence; while the other half has a fortnight's darkneſs and a fortnight's light, by turns.

The

The Earth is a moon to the Moon, waxing and waning regularly, but appearing thirteen times as big, and affording her thirteen times as much light as ſhe does to us. When ſhe changes to us, the Earth appears full to her; and when ſhe is in her firſt quarter to us, the Earth is in its third quarter to her, and *vice verſa*.

But from one half of the Moon the Earth is never ſeen at all: from the middle of the other half it is always ſeen over head; turning round almoſt thirty times as quick as the Moon does. From the circle which limits our view of the Moon, only one half of the Earth's ſide next her is ſeen; the other half being hid below the horizon of all places on that circle. To her the Earth ſeems the biggeſt body in the univerſe; for it appears 13 times as big as ſhe does to us. Her orbit croſſes the ecliptic in two oppoſite points, called the Moon's Nodes; ſo that one half of her orbit is above the ecliptic, and the other below it. The angle of obliquity is $5\frac{1}{3}$ degrees: as the Earth turns round its axis, the ſeveral continents, ſeas, and iſlands, appear to the Moon's inhabitants like ſo many ſpots of different forms and brightneſs, moving over its ſurface; but much fainter at ſome times than others, as our clouds cover them or leave them. By theſe ſpots the Lunarians can determine the time of the Earth's diurnal motion, juſt as we do the motion of the Sun: and perhaps they meaſure their time by the motion of the Earth's ſpots; for they cannot have a truer dial.

Mars. The planet Mars is next in order, being the firſt above the Earth's orbit: his diſtance from the Sun is computed to be 125,000,000 of miles; and he moves at the rate of 47,000 miles every hour: he goes round the

the Sun in 686 of our days and 23 hours; which is the length of his year, and contains 667¾ of his days; every day and night together being 40 minutes longer than with us. His diameter is 4,444 miles; and by his diurnal rotation, the inhabitants about his equator are carried 556 miles every hour. His quantity of light and heat is equal but to one half of ours; and the Sun appears but half as big to him as to us.

This planet being but a fifth part ſo big as the earth, if any moon attends him ſhe muſt be very ſmall; and has not yet been diſcovered by our beſt teleſcopes. He is of a fiery red colour; and, by his appulſes to ſome of the fixed ſtars, ſeems to be encompaſſed by a very groſs atmoſphere. He appears ſometimes gibbous, but never horned; which both ſhews that his orbit includes the Earth within it, and that he ſhines not by his own light.

To Mars, the Earth and Moon appear like two moons, a bigger and a leſs, changing places with one another, and appearing ſometimes horned, ſometimes half or three quarters illuminated, but never full; nor at moſt above one quarter of a degree from each other, altho' they are 240,000 miles aſunder.

The Earth appears almoſt as big to Mars as Venus does to us; and at Mars it is never ſeen above 48 degrees from the Sun. Sometimes it appears to paſs over the diſk of the Sun; and ſo do Mercury and Venus; but Mercury can never be ſeen from Mars by ſuch eyes as ours, unaſſiſted by proper inſtruments; and Venus will be as ſeldom ſeen as we ſee Mercury: Jupiter and Saturn are as viſible to Mars as to us. His axis is perpendicular to the ecliptic, and his orbit is two degrees inclined to it.

Jupiter,

Jupiter. Jupiter, the biggeſt of all the planets, is ſtill higher in the ſyſtem, being about 426,000,000 of miles from the Sun; and going at the rate of 25,000 miles every hour in his orbit, finiſhes his annual period in eleven of our years 314 days and 12 hours. He is above 1000 times as big as the Earth, for his diameter is 81,000 miles, which is more than ten times the diameter of the Earth.

Jupiter turns round his axis in 9 hours 56 minutes; ſo that his year contains 10,470 days; and the diurnal velocity of his equatorial parts is greater than the ſwiftneſs with which he moves in his annual orbit: a ſingular circumſtance, as far as we know. By this prodigious quick rotation, his equatorial inhabitants are carried 25,920 miles every hour (which is 920 miles an hour more than an inhabitant of this Earth's equator moves in 24 hours) beſides the 25,000 above mentioned, which is common to all his ſurface, by his annual motion.

His belts and ſpots. Jupiter is ſurrounded by faint ſubſtances, called Belts, in which ſo many changes appear, that they are generally thought to be clouds: for ſome of them have been firſt interrupted and broken, and then have vaniſhed entirely. They have ſometimes been obſerved of different breadths, and afterwards have become nearly all of the ſame breadth. Large ſpots have been ſeen in theſe belts; and when a belt vaniſhes, the contiguous ſpots diſappear with it.

He has no change of ſeaſons. The axis of Jupiter is ſo nearly perpendicular to his orbit, that he has no ſenſible change of ſeaſons: which is a great advantage, and wiſely ordered by the Author of Nature; for if this planet's axis was inclined any conſiderable

ſiderable number of degrees, juſt ſo many degrees round each pole would in their turn be almoſt ſix of our years together in darkneſs. And, as each degree of a great circle on Jupiter contains 706 of our miles at a mean rate, it is eaſy to judge what vaſt tracts of land would be rendered uninhabitable by any conſiderable inclination of his axis.

but has four moons.

The ſun appears but 1-28th part ſo big to Jupiter as to us; and his light and heat are in the ſame ſmall proportion, but compenſated by the quick returns thereof, and by four moons (ſome bigger and ſome leſs than our earth) which revolve about him; ſo that there is ſcarce any part of this huge planet but what is during the whole night enlightened by one or more of theſe moons, except his poles, whence only the fartheſt moons can be ſeen, and where their light is not wanted, becauſe the ſun conſtantly circulates in or near the horizon, and is very probably kept in view of both poles by the refraction of Jupiter's atmoſphere; which, if it be like ours, has certainly refractive power enough for that purpoſe.

Their periods round Jupiter.

The orbits of theſe moons are repreſented in this ſcheme of the ſolar ſyſtem by four ſmall circles on Jupiter's orbit; but they are drawn fifty times too large in proportion to it. The firſt moon, or that neareſt to Jupiter, goes round him in 1 day 18 hours and 36 minutes of our time; and is 229 thouſand miles diſtant from his center: The ſecond performs its revolution in three days 13 hours and 15 minutes, at 364 thouſand miles diſtance: The third in 7 days 3 hours and 59 minutes, at the diſtance of 580 thouſand miles: And the fourth, or outermoſt, in 16 days 18 hours and 30 minutes, at the diſtance of one million of miles from his center.

what ſigns it appears moſt open to us.

when Saturn is in the middle between theſe points, or in the 19th degree either of Gemini or of Sagittarius, his ring appears moſt open to us; and then its longeſt diameter is to its ſhorteſt, as 9 to 4.

Places of Saturn's nodes.

The orbit of Saturn is $2\frac{1}{2}$ degrees inclined to the ecliptic, or orbit of our earth, and interſects it in the 21ſt degree of Cancer and of Capricorn; ſo that Saturn's nodes are only 14 degrees from Jupiter's.

Georgium Sidus.

On the 13th day of March, 1781, between the hours of ten and twelve at night, as Dr. Herſchell, the Aſtronomer Royal, at Windſor, was attempting to diſcover the parallax of the ſtars, by means of double, triple, and quadruple fixed ſtars, he diſcovered a new planet, belonging to our ſyſtem, as he was examining the ſmall ſtars near the feet of Gemini, which he named Georgium Sidus, in honour to our preſent Sovereign. It is ſeldom to be ſeen very plainly by the naked eye: it is nearly the colour of Jupiter, or ſomewhat paler and more faint; and its apparent diameter about 4 ſeconds. By the calculation of M. De la Lande, we are told that his diſtance from the ſun is 19 times farther than the earth is; and its diameter is 4 1-half times that of the earth's.

It is highly probable that all the planets are inhabited.

Every perſon who looks upon, and compares the ſyſtems of moons together which belong to Jupiter and Saturn, muſt be amazed at the vaſt magnitude of theſe two planets, and the noble attendance they have in reſpect of our little earth: and can never bring himſelf to think that an infinitely wiſe Creator ſhould diſpoſe of all his animals and vegetables here, leaving the other planets bare and deſtitute of rational creatures. To ſuppoſe that he had any

view

the length of his days and nights, and the poſition of his axis, are unknown to us at preſent.

His five moons.

To Saturn, the ſun appears only 1-90th part ſo big as to us; and the light and heat he receives from the ſun are in the ſame proportion to ours. But to compenſate for the ſmall quantity of ſun-light, he has five moons, all going round him on the outſide of his ring, and nearly in the ſame plane with it. The firſt, and neareſt moon to Saturn, goes round him in one day 21 hours 19 minutes; and is 140,000 miles from his center. The ſecond, in 2 days 17 hours 40 minutes; at the diſtance of 187,000 miles. The third, in 4 days 10 hours 25 minutes; at 263,000 miles diſtance. The fourth, in 15 days 22 hours 41 minutes; at the diſtance of 600,000 miles. And the fifth, or outermoſt, at 1,800,000 miles from Saturn's center, goes round him in 72 days 7 hours 48 minutes. Their orbits, in the ſcheme of the ſolar ſyſtem, are repreſented by the five ſmall circles on Saturn's orbit; but theſe, like the orbits of the other ſatellites, are drawn fifty times too large in proportion to the orbits of their primary planets.

How the ring appears to Saturn and to us.

This ring, ſeen from Saturn, appears like a vaſt luminous arch in the heavens, as if it did not belong to the planet. When we ſee the ring moſt open, its ſhadow upon the planet is broadeſt: and from that time the ſhadow grows narrower, as the ring appears to do to us; until, by Saturn's annual motion, the ſun comes to the plane of the ring, or even with its edge; which being then directed towards us, becomes inviſible on account of its thinneſs. The ring diſappears twice in every annual revolution of Saturn, namely, when he is in the 19th degree both of Piſces and of Virgo. And

In what ſigns Saturn appears to loſe his ring; and in

and goodneſs among all his creatures! and diſtributing happneſs to innumerable ranks of various beings!

Aſtronomical Characters explained.

♈ Aries	♌ Leo	♐ Sagittary
♉ Taurus	♍ Virgo	♑ Capricorn
♊ Gemini	♎ Libra	♒ Aquarius
♋ Cancer	♏ Scorpio	♓ Piſces.

♄ Saturn	☿ Mercury	☋ Her ſouth node
♃ Jupiter	☾ Luna (the Moon)	⊖ Tellus, Terra, or the Earth
♂ Mars	☊ Moon's north node	
☉ Sol (the Sun)		
♀ Venus		

☌ Conjunction when the planets are in the ſame ſign, deg. min. &c.

✱ Sextile when 2 ſigns diſt.	△ Trine when 4 ſigns diſt.
□ Quartile when 3 ſigns diſt.	☍ Oppoſition when 6 ſigns diſt.

Eclipſes. Every planet and ſatellite is illuminated by the ſun; and caſts a ſhadow towards that point of the heaven which is oppoſite to the ſun. This ſhadow is nothing but a privation of light in the ſpace hid from the ſun by the opaque body that intercepts his rays.

When the ſun's light is ſo intercepted by the moon, that to any place of the earth the ſun appears partly or wholly covered, he is ſaid to undergo an eclipſe; tho', properly ſpeaking, it is only an eclipſe of that part of the earth where the moon's ſhadow or penumbra falls. When the earth comes between the ſun and moon, the moon falls into

into the earth's ſhadow; and having no light of her own, ſhe ſuffers a real eclipſe from the interception of the ſun's rays. When the ſun is eclipſed to us, the moon's inhabitants on the ſide next the earth (if any ſuch there be) ſee her ſhadow like a dark ſpot travelling over the earth, about twice as faſt as its equatorial parts move, and the ſame way as they move. When the moon is in an eclipſe, the ſun appears eclipſed to her, total to all thoſe parts on which the earth's ſhadow falls, and of as long continuance as they are in the ſhadow.

If the earth and ſun were equally big, the earth's ſhadow would be infinitely extended, and all of the ſame bulk; and the planet Mars, in either of its nodes, and oppoſite to the ſun, would be eclipſed in the earth's ſhadow. Were the earth bigger than the ſun, its ſhadow would increaſe in bulk the farther it extended, and would eclipſe the great planets Jupiter and Saturn, with all their moons, when they were oppoſite to the ſun. But as Mars in oppoſition never falls into the earth's ſhadow, although he is not then above 42 millions of miles from the earth, it is plain that the earth is much leſs than the ſun; for otherwiſe its ſhadow could not end in a point at ſo ſmall a diſtance. If the ſun and moon were equally big, the moon's ſhadow would go on to the earth with an equal breadth, and cover a portion of the earth's ſurface more than 2000 miles broad, even if it fell directly againſt the earth's center, as ſeen from the moon; and much more if it fell obliquely on the earth: but the moon's ſhadow is ſeldom 150 miles broad at the earth, unleſs when it falls very obliquely on the earth, in total eclipſes of the ſun. In annular eclipſes, the moon's real ſhadow ends in a point at ſome diſtance from the earth. The moon's ſmall diſtance from the earth, and the ſhortneſs of her ſhadow, prove her to be leſs than the ſun.

ſun. And as the earth's ſhadow is large enough to cover the moon, if her diameter were three times as large as it is (which is evident from her long continuance in the ſhadow when ſhe goes through its center) it is plain, that the earth is much bigger than the moon.

When there are new eclipſes.

If the moon's orbit where coincident with the plane of the ecliptic, in which the earth always moves and the ſun appears to move, the moon's ſhadow would fall upon the earth at every change, and eclipſe the ſun to ſome parts of the earth. In like manner the moon would go thro' the middle of the earth's ſhadow, and be eclipſed at every full; but with this difference, that ſhe would be totally darkened for above an hour and an half; whereas the ſun never was above four minutes totally eclipſed by the interpoſition of the moon. But one half of the moon's orbit is elevated 5 1-3d degrees above the ecliptic, and the other half as much depreſſed below it; conſequently, the moon's orbit interſects the ecliptic in two oppoſite points, called the moon's nodes, as has been already taken notice of. When theſe points are in a right line with the center of the ſun at new or full moon, the ſun, moon, and earth are all in a right line; and if the moon be then new, her ſhadow falls upon the earth; if full, the earth's ſhadow falls upon her. When the ſun and moon are more than 17 degrees from either of the nodes at the time of conjunction, the moon is then generally too high or too low in her orbit to caſt any part of her ſhadow upon the earth. And when the ſun is more than 12 degrees from either of the nodes at the time of full moon, the moon is generally too high or too low in her orbit to go through any part of the earth's ſhadow: and in both theſe caſes there will be no eclipſe. But when the moon is leſs than 17 degrees from either node at the time

The moon's nodes.

Limits of eclipſes.

time of conjunction, her ſhadow or penumbra falls more or leſs upon the earth as ſhe is more or leſs within this limit. This admits of ſome variation; for, in apogeal eclipſes, the ſolar limit is but 16 1-half degrees; and in perigeal eclipſes it is 18 1-3d. When the full moon is in her apogee, ſhe will be eclipſed if ſhe be within 10 1-half degrees of the node; and when ſhe is full in her perigee, ſhe will be eclipſed if ſhe be within 12 1-30th degrees of the node. And when ſhe is leſs than 12 degrees from either node at the time of oppoſition, ſhe goes through a greater or leſs portion of the earth's ſhadow as ſhe is more or leſs within this limit. Her orbit contains 360 degrees; of which 17, the limit of ſolar eclipſes on either ſide of the nodes, and 12 the limit of lunar eclipſes, are but ſmall portions: and as the ſun commonly paſſes by the nodes but twice in a year, it is no wonder that we have ſo many new and full moons without eclipſes.

To illuſtrate this, let A B C D be the ecliptic, R S T U a circle lying in the ſame plane with the ecliptic, and V W X Y, the moon's orbit, all thrown into an oblique view, which gives them an elliptical ſhape to the eye. One half the moon's orbit, as V W X, is always below the ecliptic, and the other half X Y V above it. The points V and X, where the moon's orbit interſects the circle R S T U, which lies even with the ecliptic, are the moon's nodes; and the right line, as X E V, drawn from one ſide to the other thro' the earth's center, is called the line of the nodes; which is carried almoſt parallel to itſelf round to the ſun in a year. Plate XX. Fig. 1. Line of the nodes.

If the moon moved round the earth in the orbit R S T U which is coincident with the plane of the

ecliptic, her ſhadow would fall upon the earth every time ſhe is in conjunction with the ſun; and at every oppoſition ſhe would go through the earth's ſhadow. Were this the caſe, the ſun would be eclipſed at every change, and the moon at every full, as already mentioned.

But although the moon's ſhadow N muſt fall upon the earth at a, when the earth is at E, and the moon in conjunction with the ſun at i, becauſe ſhe is then very near one of her nodes; and at her oppoſition n ſhe muſt go through the earth's ſhadow I, becauſe ſhe is then near the other node; yet, in the time that ſhe goes round the earth to her next change, according to the order of the letters X Y V W, the earth advances from E to e, according to the order of the letters E F G H; and the line of the nodes V E X being carried nearly parallel to itſelf, brings the point f of the moon's orbit in conjunction with the ſun at the next change; and then the moon being at f, is too high above the *eclipſe* to caſt her ſhadow on the earth: and as the earth is ſtill moving forward, the moon at her next oppoſition will be at g, too far below the ecliptic to go through any part of the earth's ſhadow; for by that time the point g will be at a conſiderable diſtance from the earth, as ſeen from the ſun.

When the earth comes to F, the moon in conjunction with the ſun Z is not at k, in a plane coincident with the ecliptic, but above it at Y, in the higheſt part of her orbit: and then the point b of her ſhadow O goes far above the earth, as in fig. 2, which is an edge-view of fig. 1. The moon at her next oppoſition is not at o, fig. 1, but at W, where the earth's ſhadow goes far above her, as in fig. 2. In both theſe caſes the *line* of

the

the nodes V F X, fig. 1, is about 90 degrees from the ſun, and both luminaries are as far as poſſible from the limits of eclipſes.

When the earth has gone half round the ecliptic from E to G, the line of the nodes V G X is nearly, if not exactly, directed towards the ſun at Z; and then the new moon I caſts her ſhadow P on the earth G; and the full moon p goes through the earth's ſhadow L; which brings on eclipſes again, as when the earth was at E.

When the earth comes to H, the new moon falls not at m in a plane coincident with the ecliptic C D, but at W in her orbit below it: and then her ſhadow Q fig. 2, goes far below the earth. At the next full ſhe is not at q, fig. 1, but at Y in her orbit 5 1-3d degrees above q, and at her greateſt height above the ecliptic C D; being then as far as poſſible, at any oppoſition, from the earth's ſhadow M, as in fig. 2.

So when the earth is at E and G, the moon is about her nodes at new and full; and in her greateſt north and ſouth declination (or latitude, as it is generally called) from the ecliptic at her quarters: but when the earth is at F or H, the moon is in her greateſt north and ſouth declination from the ecliptic at new and her full, and in the nodes about her quarters.

The point X where the moon's orbit croſſes the ecliptic, is called the aſcending node, becauſe the moon aſcends from it above the ecliptic: and the oppoſite point of interſection V is called the deſcending node, becauſe the moon deſcends from it below the ecliptic. When the moon is at Y, in the higheſt point of her orbit, ſhe is

The moon's aſcending and deſcending node.

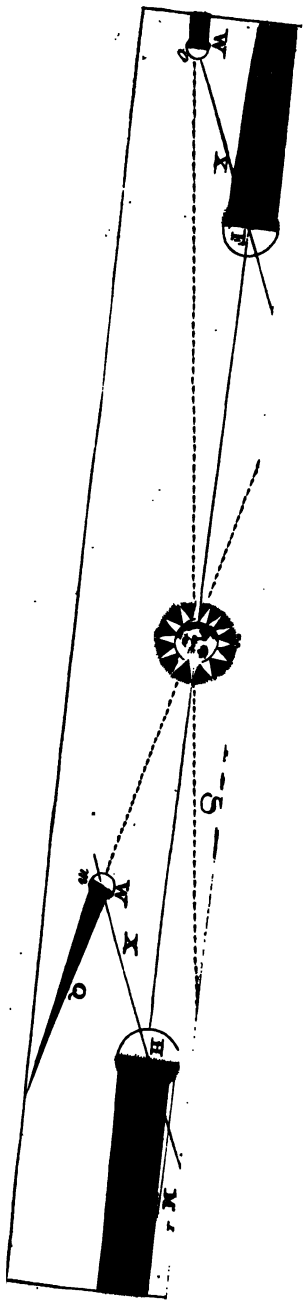
Her north and ſouth latitude.

in her greateſt north latitude; and when ſhe is at W, in the loweſt point of her orbit, ſhe is in her greateſt ſouth latitude.

The nodes have a retrograde motion;

If the line of nodes, like the earth's axis, was carried parallel to itſelf round the ſun, there would be juſt half a year between the conjunctions of the ſun and nodes. But the nodes ſhift backward, or contrary to the earth's annual motion, 19 1-third degrees every year; and therefore the ſame node comes round the ſun 19 days ſooner every year than on the year before. Conſequently, from the time that the aſcending node X (when the earth is at E) paſſes by the ſun as ſeen from the earth, it is only 173 days (not half a year) till the deſcending node V paſſes him. Therefore, in whatever time of the year we have eclipſes of the luminaries about either node, we may be ſure, that in 173 days afterward, we ſhall have eclipſes about the other node. And when at any time of the year the line of the nodes is in the ſituation V G X, at the ſame time next year it will be in the ſituation r G s; the aſcending node having gone backward, *i. e.* contrary to the order of ſigns, from X to s, and the deſcending node from V to r; each 19 1-3d degrees. At this rate the nodes ſhift through all the ſigns and degrees of the ecliptic in 18 years and 225 days; in which time there would always be a regular period of eclipſes, if any complete number of lunations were finiſhed without a fraction. But this never happens; for if both the ſun and moon ſhould ſtart from a line of conjuction with either of the nodes in any point of the ecliptic, the ſun would perform 18 annual revolutions and 222 degrees over and above, and the moon 230 lunations and 85 degrees of the 231ſt, by the time the node came round to the ſame point of the ecliptic again;

which brings on the eclipſes ſooner every year than they would be if the nodes had not ſuch a motion.



A period eclipses.

The nodes have a retrograde motion;

which brings on the eclipſes ſooner every year than they would be if the nodes had not ſuch a motion.

again; ſo that the ſun would then be 138 degrees from the node, and the moon 85 degrees from the ſun.

A period of eclipſes.

But, in 223 mean lunations, after the ſun, moon, and nodes, have been once in a line of conjunction, they return ſo nearly to the ſame ſtate again, as that the ſame node, which was in conjunction with the ſun and moon at the beginning of the firſt of theſe lunations, will be within 28 degrees 12 ſeconds of a degree of a line of conjunction with the ſun and moon again, when the laſt of theſe lunations is completed. And therefore, in that time, there will be a regular period of eclipſes, or returns of the ſame eclipſe, for many ages.

On the UNIVERSE.

THIS wide machine the univerſe regard,
With how much ſkill is each apartment rear'd!
The ſun a globe of fire, a glowing maſs,
Hotter than melting flint or fluid glaſs.
Of this our ſyſtem holds the middle place.
Mercury, the neareſt to the central ſun,
Does in an oval orbit circling run;
But rarely is the object of our ſight:
In ſolar glory ſunk, and more prevailing light.

Venus

Venus the next, whoſe lovely beams adorn
As will the dewy eve as op'ning morn,
Does in her orb in beauteous order turn.
The Globe Terreſtrial next, with ſlanting poles,
And all its ponderous load unweary'd rolls.
Mars next in order, farther from the ſun,
Does in a more extenſive orbit run.
Then we behold bright planetary Jove,
Sublime in ſpace, thro' his wide province move;
Four ſecond planets his dominion own,
And round him turn, as round the earth the moon.
Saturn revolving in a higher ſphere,
Is by five moons attended thro' his year.
The vaſt dimenſion of his path, is found
Five thouſand million Engliſh miles around.
Then Georgium Sidus, fartheſt from the Sun,
In boundleſs ſpace does round his orbit turn.

Yet is this mighty ſyſtem, which contains
So many worlds, ſuch vaſt æthereal planes,
But one of thouſands which compoſe the whole;
Perhaps as glorious, and of worlds as full!
The ſtars which grace the high expanſion, bright,
By their own beams and unprecarious light,
Tho' ſome near neighbours ſeem, and ſome diſplay
United luſtre in the milky way,
At a vaſt diſtance from each other lie,
Sever'd by ſpacious voids of liquid ſky.—
All theſe illuſtrious worlds, and many more,
Which by the tube aſtronomers explore;
And millions which the glaſs can n'er deſcry,
Loſt in the wilds of vaſt immenſity,

Are

Are ſuns, are centers, whoſe ſuperior ſway,
Planets of various magnitudes obey.

If we with one clear comprehenſive ſight
Saw all theſe ſyſtems, all theſe orbs of light;
If we their order and dependence knew,
Had all their motions and their ends in view,
With all the comets which in either ſtray,
Yet conſtant to their time and to their way,
Would not this view convincing marks impart
Of perfect wiſdom and ſtupendous art!

FINIS.

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